Additional Data Layers and Data Sources

This section describes data obtained from other sources or from the Oswegatchie and Black watershed project (Roy et al. 1997). A secondary goal of the project was to collect useful or improved environmental data layers created by other sources. No deficiencies in the APA data sets at the start of the project were in the scale of available Digital Elevation Models (DEMs), and lack of tax parcel data for Warren County. These were supplemented during the project with new DEM's from the NYS DEC, and new parcel information from Warren County. Additional data layers were obtained from New York State Gap Analysis Program (GAP) at Cornell University, the Lake Champlain Basin Program (LCBP), and the USGS. Finally, surface and bedrock geology maps obtained as part of the Oswegatchie/Black projects, and APA soil maps were used in analysis. The GAP program, sponsored by the Federal government in each state, is intended to identify sui habitat for vertebrate species using Thematic Mapper Satellite imagery to produce a detailed map of upland land cover. The LCBP has mapped watersheds in the Lake Champlain basin on a similar scale as this project. Although these watersheds are based on stream intersections, not on ponds, they may prove to be reasonably equivalent to watersheds produced in this project and the OB project.

The Adirondack Park Agency GIS Lookup System

The New York State Adirondack Park Agency's GIS Lookup System enables staff to retrieve natural resource and ownership information through a simple, customized menu system. All inquires under review by the Adirondack Park Agency are referenced with a tax map parcel number. In the past, Agency staff had to make phone calls to county real property tax offices to collect descriptive information about parcels. Staff then had to get the paper tax map, photo-copy it (a 40"x32" map), and hand plot and re-scale the boundaries to other resource maps such as wetlands and zoning. The GIS Lookup System now provides all of this information. Lookup System features include the ability to search and map parcel ownership by any portion of an owner's name, search and map parcels by tax map number lists; find past APA transactions including permit review, jurisdictional inquiries, and enforcement locations; find and map natural and cultural place names (populated places, streams, lakes, summits, etc.); and to identify tax

parcels, past projects, general soils, Adirondack Lake Survey pond data, and map features by point and query. For some of the data layers, an additional menu appears asking the user if one or many features will be identified, or if the user wants to draw a box or polygon around the desired features.

This computer database lookup system provides Agency personnel with quick access to many kinds of data. It is an ideal method for delivering new information on where sensitive resources exist, and what resources are sensitive.

Digital Elevation Models

Digital Elevation Models (DEMs) are representations of topographic map elevations as a digital grid of cells in which each cell contains an estimate of elevation for a particular point. DEMs can be used to create maps, to find drainage pathways, calculate slope and aspect, and estimate the boundary of the watershed draining through a selected point. They are limited by the original scale and accuracy of the information used to construct them.

Until recently, the best digital elevation information for the Adirondack Park was coarse resolution 1:250000 scale DEMs (~70 meter cell size), created by the Defense Mapping Agency. These DEMs were inappropriate to use with the wetland and watershed map data layers created for this project at a scale of 1:24000. In many cases, the DEM grid cells were actually larger than the smaller watersheds. The coarse resolution of these DEMs makes them unusable for environmental analysis with the other fine-scale information generated in this project.

New digital elevation models were finished by the NYS DEC Division of Water at 1:24000 scale in 1998. All 200 quadrangle coverages necessary for the Adirondack Park were obtained from the Cornell University Geographic Information Repository (CUGIR) website (http://cugir.mannlib.cornell.edu/index.html). A representative sample was checked against existing paper and digital contour and surface water hydrology maps, and was found to match well. Metadata for these DEM grids is available at the CUGIR website.

The 1998 DEMs were used in this project to make an additional evaluation of the manually delineated OB watersheds. For each manually delineated watershed, a new watershed was generated from the DEMs using a procedure that will be described more fully below. As a

result of this comparison, a protocol was established for using the fire-scaled DEMs to generate watersheds in areas that have not been delineated, or for watersheds that were not included in previous watershed mapping efforts.

After the DEM quadrangles were evaluated, they were immediately used to generate several new data layers. New data layers included digital 20 foot contour vector coverages that were immediately added to the Agency Lookup System. Slope and aspect data were generated for each watershed in the OB and UH dataset for use in environmental analysis. DEMs also were used to generate temperature and precipitation grids using model results from Ollinger et al. (1993) as described more fully below.

Tax Map Data

Tax parcel data provides information regarding land use, from which potential human impact can be inferred. It shows the location, type of activity, and the approximate date of construction for each parcel included in the database. There are 12 counties wholly or partly in the Park. Of these, tax parcel information from the New York State Office of Real Property (ORPS) is currently available for all but Warren County. The tax parcel information includes coordinate information for the location of the center of the tax parcel, not the boundaries of the parcel. These parcel centroid points are associated with a database of information that includes town, tax parcel identification numbers, age of construction, parcel tax class, and other information about the parcel. Tax parcel centroids, and the associated information is used by the Agency Lookup System as a key to project locations.

Lack of tax map information for Warren County at the beginning of the project made it difficult to examine the potential for human impacts using GIS. Warren County, one of the most heavily developed counties in the Park, is where human impacts to wetlands and waterbodies are likely to be most evident in the Upper Hudson watershed.

Preliminary parcel centroid information was obtained from Warren County in the middle of the third year of the project. The County is in the process of updating old parcel boundaries and changing parcel numbers to reflect current state standards, and updated tax data will not be available until mid-2000. Preliminary data consisted of old parcel centroids joined to unchecked

new ORPS data for this project. These data, combined with other tax map parcel information, were used in evaluating potential human impacts.

A major difficulty in working with parcel centroid information is that parcel centroids do not show the parcel boundary, and are not located at the point at which the impact is being created. Where parcels are long and thin, or large, the structure likely to be causing impact is probably not located near the center of the parcel. This is especially true when the parcel is near a waterbody where direct access to the lake is an important factor in evaluating the human impact of the activities on the parcel. In these situations, the structures are likely to be near the lake shore, not the parcel centroid. Although this information can be inferred from some parcel centroids, it would be of great benefit to have the parcel boundaries in addition to the parcel centroids. Digital parcel boundaries are likely to be available for Warren County in the near future. In an effort to supply parcel boundaries for other counties, the Park Agency had scanned individual tax map sheets for Essex County. As part of this project, these sheets were georeferenced, projected, and made part of the Agency Lookup System. Digital tax map boundaries should be acquired as they become available.

Surface and Bedrock Geology

Digital maps of the Park surface and bedrock geology were collected as part of the Oswegatchie/Black watershed mapping project, and used as sources of environmental data in this project. These maps were compiled from the work of various researchers (see http://www.northnet.org/adirondackparkagency/OB2/HtmlDocs/siteindx.htm under geology for a list of references) and published by the New York State Museum as paper maps (see http://www.nysl.nysed.gov/gis/ for metadata relating to these maps) at a scale of 1:250000. The surface and bedrock maps were later converted to digital form as separate digital map sheets. For this project, these were joined into one digital coverage because the digital maps were not edge matched when they were created.

As part of the OB project, the buffering capacity of the bedrock rock types were interpreted by Dr. David A. Franzi at SUNY Plattsburgh. (personal communication) and Dr. Phil Whitney (personal comminication) of the New York State Museum supplied interpretation for

those bedrock types in the UH watershed area that were not present on the OB watershed for this project. Both maps were overlaid on the digital OB and UH watershed maps and information was extracted for each watershed and added to the database created for the environmental analysis described below.

Meso Soils Map

The APA has been collecting digital maps of the Park's natural features for some time. Because the Park is not prime agricultural land, the Adirondacks have been classified as low priority by the USDA Natural Resource Conservation Service (formerly the Soil Conservation Service) for detailed soil map creation. The best available digital soil maps were prepared for the APA in 1975 by the USDA Soil Conservation Service as part of their assistance to county soil and water conservation districts in cooperation with Cornell University Agricultural Station on a 1:62500 base map supplied by the State of New York Office of Planning Coordination. This map is commonly referred to as the "meso" soils map.

The meso soil map was designed as a broad planning tool and, as such, lacks the resolution of more detailed soil surveys. It was created at a coarse scale (1:62500) compared to most county soil maps (1:16400), with a large minimum mapping unit (40 to 500 acres) at the soil association level. There are also some differences associated with soil type matches across county boundaries. Combined, these limitations mean that only broad patterns of soil development are described in the map, and that the map is not appropriate for either site level soil property determinations or use in modeling projects that assume fine resolution of soil properties.

Park wide, 132 map units, or soil associations, have been identified. Estimates of many soil parameters are included with this data, including slope, depth to bedrock, erosion characteristics (K-factor), and parent material, among others.

USGS Gaging Station Data

The United States Geological Survey (USGS) operates stream gaging stations that monitor daily stream discharge at various points around the Adirondack Park. These data are an important source of information on the hydrologic functioning of the landscape. Gaging station

information for the Adirondack Park was obtained from the New York NWIS-W web site at http://waterdata.usgs.gov/nwis-w/NY/ . Location data in the files were used to create a GIS data set of gaging station locations. This information was overlaid on the watershed maps and used to compute pond flushing rates as described below.

Lake Champlain Basin Program Data

The Lake Champlain Basin Program (LCBP) is a federal, state and local initiative to restore and protect Lake Champlain and its surrounding watershed for future generations. It was instituted in 1990 as a way to promote the health of Lake Champlain. As part of this program, a watershed map and several other map layers have been or are being created that may be equivalent to layers created by this project.

One of the main efforts of the Lake Champlain Basin Program is to identify sources of phosphorus entering Lake Champlain. This was accomplished through the application of Eutromod, a model designed to estimate the amount of phosphorus released from a variety of land use practices in small watersheds (Rechow 1990). Eutromod is a watershed based model that predicts nutrient concentrations as a function of area in each land use type. Therefore, the LCBP created a detailed sub-watershed map of the Lake Champlain basin that was obtained for evaluation.

The watershed mapping strategy of the APA series of watershed projects has been to map watersheds delineated from the outlet of ponds that have been given NYS DEC pond numbers. This strategy is based on linking pond chemistry data from the Adirondack Lakes Survey Corporation (ALSC) gathered since the 1980's with land use and land condition (soils, geology and others) data so that pond water quality can be evaluated using GIS models.

The LCBP watershed layers originated from the USGS eleven-digit hydrologic unit data that were modified to fit LCBP needs. The LCBP watershed layer appears to be based on stream intersections, not on pond outlets, and differs from the pond-based watersheds in the ALSC database. If there are only small differences between the stream intersections and the outlet of the DEC numbered ponds, these watersheds may prove acceptable, and the effort of creating an

additional watershed layer for the Lake Champlain Basin in the Adirondack Park may not be necessary.

Other layers currently available or available in the near future from the LCBP include upland land cover and wetlands. Wetland maps are in production, but have not been completed as of this writing. Upland land cover was obtained, but no evaluation was conducted.

Gap Analysis Program

One of the early products of the New York State Gap Analysis Program (GAP) project was a detailed vegetation map of the State of New York. The Gap Analysis Program (GAP) is under the direction of the National Biological Service of the U.S. Department of the Interior. The GAP project is a national effort to systematically inventory and plot the distribution of plant and animal species in the U.S. It represents the first comprehensive effort to inventory our national biodiversity, and to record this information in digital map form. The New York State Gap Analysis Project (NYGAP) is coordinated through the NY Cooperative Fish and Wildlife Research Unit (USDI, NBS), located in Cornell's Department of Natural Resources. The Adirondack Park Agency is one of the cooperators on this project.

The goal of the GAP project is to identify gaps in conservation programs based on GIS maps of vegetation types. Using GIS, distributions of butterflies, amphibians, reptiles, birds, mammals and threatened, endangered, or sensitive species are mapped as a function of the vegetation types in which they are found.

The implementation of gap analysis depends on the technology geographic information systems (GIS). Conservation biologists have been using GIS to identify critical areas for the protection of endangered species by comparing the extent of existing reserves with the range of the species of interest. Unprotected sui habitat represents gaps in the protection of these species. Once identified, these areas can be incorporated into future protection efforts.

The GAP vegetation map offers several advantages over the upland land cover map created for this project. The GAP map was created using a detailed hierarchical vegetation classification system with several levels of aggregated vegetation types. The top levels of this classification are equivalent to the classification system used in this project, while the more

detailed levels of the classification offer a finer view of the landscape. The GAP vegetation map covers the entire Park, including the area outside of the upland land cover maps created for the series of EPA projects. It was intensively evaluated on the computer and in the field before it was released. Because of these advantages, the GAP vegetation map has the potential to provide an upland vegetation map that is at least the equivalent of what is being produced for this project, and eliminate the need to produce upland classification maps for the major watershed basins in the Park for which equivalent upland
land cover maps have not yet been produced. This should be investigated before further upland classifications are started.

Data Verification

A major goal of this project was to find ways to use the new and existing digital data maps to improve protection of natural resources in the Adirondack Park. In order to use these data for uses other than mapping, the information in the layers must be verified. This section reports efforts to verify information in the wetland and watershed map layers created for this project both in the field, and through comparison with other data sources.

Wetlands map

Introduction

The Upper Hudson watershed covers approximately 680000 hectares. Aerial photography was used to delineate wetlands in the Upper Hudson Basin because it can be used to classify large areas, can be accomplished in a reasonable period of time, can be duplicated, is more economical than mapping in the field, and can be verified.

There are limitations on the accuracy of wetland delineations using aerial photography. Many wetlands are located on gradually sloping terrain, where determining the wetland boundary with aerial photography is difficult. Identification of specific vegetation cover types also can be difficult, and may be affected by the difference in time between when the photography was collected and when the interpretation was conducted. Verifying the location of wetland boundaries and cover type labels for wetland polygons is time consuming, expensive, and difficult even though new technology such as Geographic Positioning Systems (GPS) has greatly improved the efficiency with which ground truth information can be gathered. Therefore, field visits were made only to selected watersheds and other areas for the purpose of validating wetland cover type and wetland boundary location.

Method

Various wetland were field verified in selected watersheds in the Adirondack Lakes Survey Corporation's (ALSC) Adirondack Long Term Monitoring (ALTM) study. There are eight ALTM watersheds in the Upper Hudson (UH) watershed. Water chemistry in these lakes has been sampled monthly since 1992. These watersheds were chosen because it was felt that improved information on the wetland condition of these watersheds would be useful for other studies. Wetlands along routes to these watersheds were also included in the verification study

based on ease of access while visiting the ALTM watersheds, or potential proximity to human impact (Figure 8).

Maps for use in the field were produced using the digital wetland boundary and cover type maps prepared as part of this project and overlayed on digital USGS planimetric quadrangle

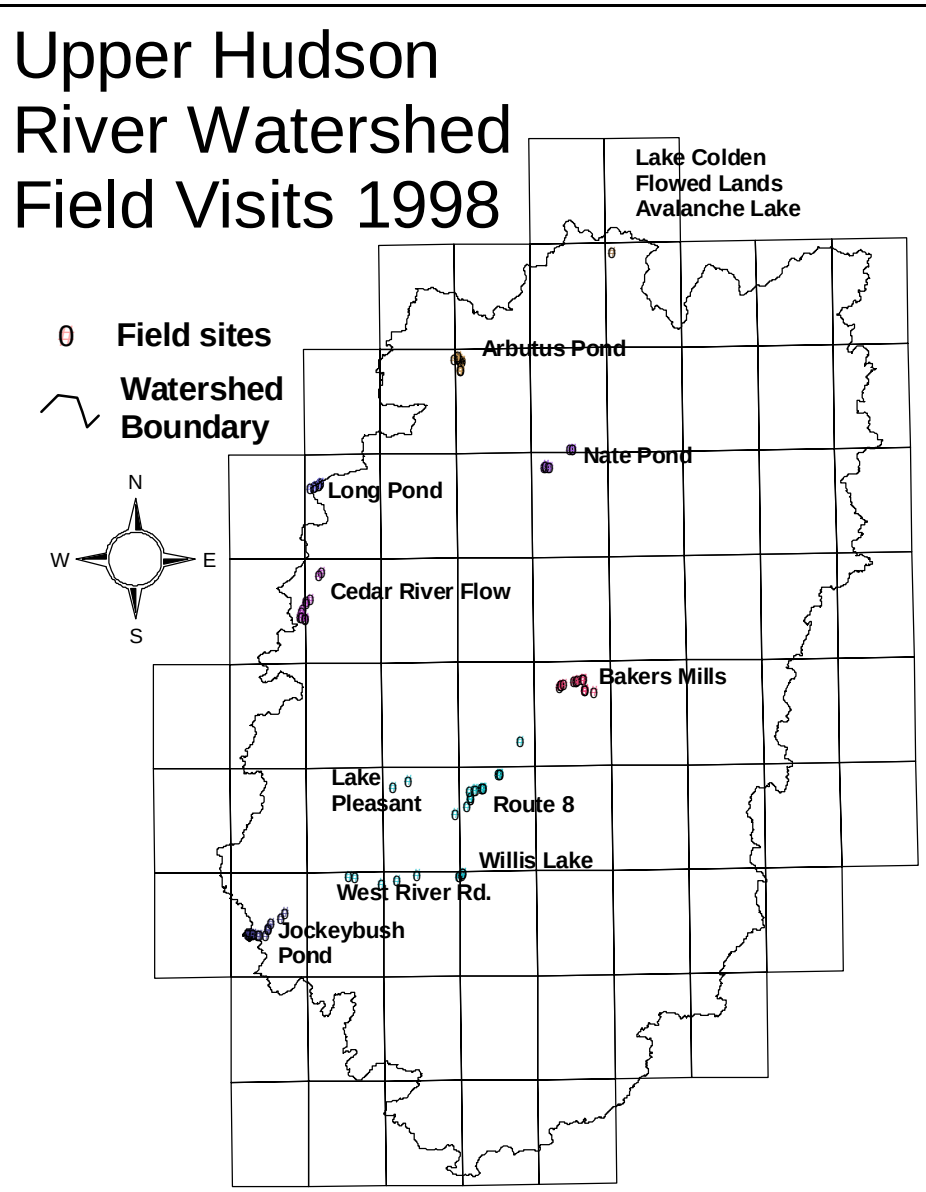


Figure 8. Location of Wetland Verification Sampling Sites.

maps. Field site locations were recorded using a Trimble Pathfinder Basic GPS unit with remote antenna. At each field visit, several wetlands were visited. At each location, a GPS point was collected, along with photographs of the field site and general description of the vegetation.

The GPS location data points were processed using Trimble Pathfinder software and transferred to Arc-Info. Using Arc-Info, a map was created with field data and photos linked to discrete points on the map (Figure 9). This map was overlaid on the wetlands maps to identify differences in wetland boundary location and vegetation type. Differences were discussed with other APA staff and personnel at the Remote Sensing Laboratory at SUNY, Plattsburgh who were responsible for the aerial photography interpretation used to create the digital wetlands maps. Each area where there was a significant difference was investigated on the original imagery and on the intermediate materials.

Results and Conclusions

The location of wetland boundaries for the majority of boundaries checked was within the tolerance of mapping conventions. Boundaries on the digital maps were significantly different than what was found in the field where topography was difficult to interpret on the imagery. Significant wetland boundary differences were also found where change had occurred in the period between when the aerial imagery was collected and the field visits, such as where there were young rapidly growing trees. Where wetlands were indicated on the wetlands map, wetlands were almost always present in the field. Some wetlands were found that were not present on the wetlands map, particularly in forested areas, where ground conditions were not easily seen from the aerial photography. Where cover types differed between the wetlands map and the field interpretation, the difference was often due to growth of trees in shrub scrub wetlands, or disagreement on the location of the boundary between forested wetland types. Field investigation found more emergent marsh than was present on the wetland maps, but this was expected because the imagery used to prepare the wetland maps was taken early in the growing season, before emergent vegetation had time to develop.

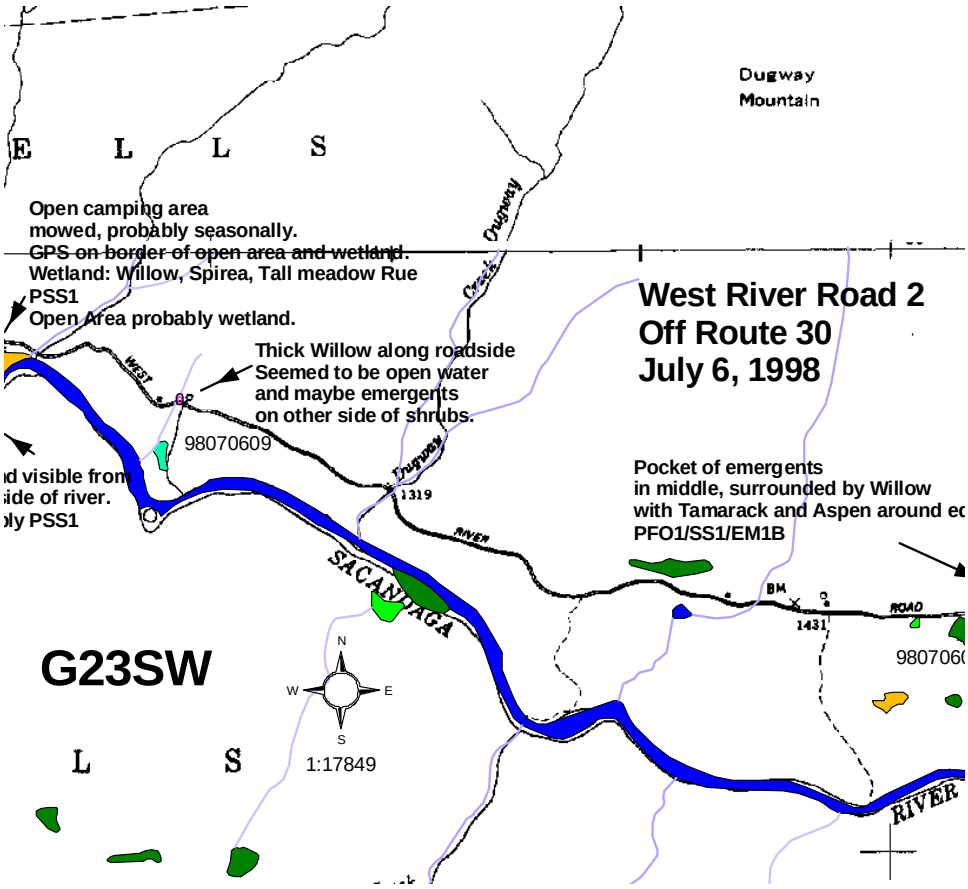


Figure 9. Sampling Location along the Sacandaga River. The figure shows an example field map with notes and GPS points from a field visit.

Watershed Delineation Comparison

Introduction

Watersheds are a basic ecological and geochemical unit. Water, beginning as precipitation, is altered by the soil, surface geology, bedrock, and vegetation through which it passes on its way to lakes, ponds, or streams. Identifying the area of the watershed that flows through a pour point is an important step towards understanding the chemistry and biology of the aquatic systems in the watershed.

A pour point is the location past which water flows as it exits a watershed. Pour points can be chosen anywhere it is useful to define them; at stream junctions, at pond inlets or outlets, or locations along a stream or river. The surface watershed of a pour point is the total area through which water moves on its way past the pour point.

The Adirondack Lakes Survey Corporation (ALSC) collected physical and chemical data for over 1500 ponds and lakes during the 1980's (Baker et al. 1990). Watersheds for these lakes and ponds were delineated manually on mylar overlays on 15 minute USGS topographic maps. Watershed area was determined using a graph paper background and counting the squares covered by the watershed on the graph paper (ALSC 1985). Since then, larger scale USGS topographic maps have become available, and in a previous EPA funded watershed project (Roy et al. 1997), these were used to manually delineate watersheds for ponds and lakes with New York State Department of Conservation (DEC) pond numbers. Watersheds were delineated on paper 1:24000 scale or 1:25000 scale USGS maps by two different parties. The differences between them were rectified by a third party, and watershed boundaries were digitized and edge matched. The same process was repeated for the Upper Hudson, and is described in detail in an earlier section of this report.

Digital elevation models (DEMs) provide a digital raster version of contour lines on USGS paper maps. In 1998, the DEC released new 1:24000 scale DEMs based on 10 meter square grid cells (see section above for description). DEMs can be used to quickly obtain the watershed of any chosen point by finding all the cells in the DEM that drain through that point. There are limitations to the use of DEMs to delineate watersheds that are very small and in areas where the general topography demonstrates low relief. The new DEMs were used to check the manual watershed delineations based on paper topographic maps in the Oswegatchie and Black

watersheds. Based upon the results of this comparison it may be appropriate to delineate watersheds in sui areas that have not already been delineated manually. This section discusses methods used to generate watersheds in the Oswegatchie and Black watersheds.

Methods

An Arc-Info macro program was written using internal identification numbers to sequentially select each of the subwatersheds from the digital map of Oswegatchie and Black (OB) subwatersheds. For each subwatershed the appropriate DEMs were selected and appended. The polygon representing the subwatershed was buffered to include areas outside the polygon that might be included in the digital watershed by the digital delineation process that were not included in the manual delineation process. This area was clipped from the DEM, and the watershed of the lowest point in the unbuffered polygon was delineated using the DEM. The new digitally created DEM subwatersheds were appended together in an Arc-Info region format, and the area of the resulting watersheds was exported to an EXCEL spreadsheet. For the subwatersheds included in the ALSC study, the area of the ALSC, manually delineated and DEM subwatersheds were compared. Also, for these subwatersheds, the polygons in the manual and DEM delineations were compared by visual inspection.

Results

Visual inspection showed that many of the manual and DEM watersheds were virtually the same. There were minor differences in the exact boundary of the two polygons where slightly different pathways were taken descending a ridge line. In other places, there were larger differences where the DEM delineation chose a completely different ridge line. In some cases, these were the result of errors on the part of the manual delineators. Differences also occurred at the lower end of the watershed where the algorithm for choosing the pour point in the DEM delineation chose a point slightly different from that chosen in the manual delineation. Where the pour point was in or near a large body of water, represented as a flat area in the DEM, the DEM delineation inserted a topographic divide into the flat water, and had difficulty finding the full watershed. Small watersheds in flat terrain were particularly difficult to delineate, and there were often large differences in the shape and area of the watershed between the two watershed polygons.

All of the watershed polygons in which there was a difference attribu to flat terrain or poorly placed pour points, or were not included in the ALSC sampling were removed from the dataset, and the areas compared. Of the remaining 391 watersheds, the area of over 80 percent of the DEM and OB watersheds were within 10 percent of each other.

Discussion

The new manually delineated watershed boundaries for the Oswegatchie, Black, and Upper Hudson watersheds are obviously an improvement over the older ALSC watersheds. The higher rate of agreement between the OB and the DEM derived watershed areas suggests that the areas and polygons derived from each method are equivalent for most uses, and the manually digitized watershed polygons should be retained in the Agency resource map database. However, the methods used for creating the manually delineated watershed boundaries are overly time consuming. They include delineating, rectifying, digitizing, and finally edge matching boundaries. Many of these steps involve interpretation of the map, and manual transfer of lines between steps where the lines may be inadvertently moved. This method has only one consistent advantage over using DEMs to create watershed boundaries: the interpreter can include the effects of roads and other human changes to the environment in the watershed boundary. The ease with which watershed polygons can be obtained in a short time using the DEMs for any chosen pour point suggests that they should be used to obtain watershed boundaries where there are no liabilities in using them. The DEM derived watershed boundaries will be suspect in flat areas and where the pour point is located on or near a body of water. DEM watersheds can be evaluated by displaying them on a background of contour lines also derived from the DEM, and planimetric maps of roads and other human development artifacts. Where the topography for using the DEM is poor, or there is obvious interference in the drainage pattern from roads and other development, the watershed line can be changed manually on the screen.

One of the goals of this project was to use watershed maps in conjunction with other digital natural resource and land use maps to examine the effect of human impacts in the watershed. The watershed pour points were chosen with the aim of leveraging the best available data, i.e., the ponds sampled by the ALSC since 1980's. The OB and Upper Hudson watershed maps are very good for obtaining upland watershed information for these purposes.

Data analysis

Flushing Rate Recalculation

Introduction

During the 1980's, the Adirondack Lake Survey Corporation (ALSC) calculated lake volume, watershed area, and runoff per unit area for 1497 lakes in the Adirondacks as part a larger effort to document the effects of acid precipitation on lake chemistry and biology in the Adirondack Park (Baker et al. 1990). These data were used to calculate flushing rates for these lakes. The same source data for runoff per unit area has been applied to lakes not sampled by ALSC where necessary.

Flushing rate is a key parameter in lake nutrient loading models, and in lake acidification management issues such as how quickly a lake will re-acidify after treatment with lime. The best methods available at the time were used by the ALSC to calculate flushing rate. Current methods for making these calculations, and the data available with which to make them, have improved. This section describes methods used to create the original ALSC estimates, and new estimates of flushing rates for ALSC sampled ponds that are in the Upper Hudson, Oswegatchie, and Black watersheds using watershed areas and estimates of runoff prepared with new data.

Flushing rate (ρ) is the theoretical rate at which water in a lake is replaced by precipitation falling in the watershed on an annual basis. It is a function of lake volume, watershed area, and, neglecting long-term changes in groundwater storage, precipitation minus evapotranspiration, or runoff. Flushing rate is calculated as:

Flushing rate = (watershed area * runoff per unit time) / lake volume.

Lake volume is only available from the ALSC data (ALSC 1985) and was not changed for this project. New watershed areas from the watershed maps created for the Upper Hudson in this project, and for the Oswegatchie and Black River watersheds from Roy et al. (1997) were used. Runoff is a function of temperature and precipitation. New estimates of mean monthly temperature and precipitation were calculated for each DEM cell in each watershed using the approach of Ollinger et al. (1993), and new 10 meter 1:24000 scale DEMs. The mean temperature and precipitation value for each month for all the DEM grid cells in each watershed

were used to estimate evapotranspiration using Thornthwaite et al.(1944). Evapotranspiration was subtracted from total precipitation and the remaining precipitation was treated as runoff.

Lake Volume

Lake volume was calculated from existing lake bathymetry or from maps developed by the ALSC at the time of the survey. The procedures used to obtain estimates of lake volume from lake bathymetry are described in the ALSC manual of standard operating procedures (ALSC 1985), and can be briefly summarized as the sum of the volumes between each bathymetric contour line.

Watershed Area

Watershed areas in the original ALSC database were calculated by delineating them on mylar using USGS 15 minute, 1:62500 scale maps. The mylar drawing of each watershed was measured separately utilizing graph paper to estimate area separately and a digital file was produced..

The lakes sampled by the ALSC were used as the basis for the digital watershed maps prepared for this project. There are 680 watersheds in common between the ALSC and digital watershed datasets. New digital watershed maps were produced as part of this project and the OB project (Roy et al. 1997) that were based on USGS 1:24000 scale 7.5 minute and 1:25000 scale 7.5 minute x 15 minute topographic maps. Watersheds for the Upper Hudson, Oswegatchie, and Black Rivers were delineated by hand onto these maps, digitized as separate quadrangle based Arc-Info coverages, and appended together. Watershed areas derived from these digital maps were compared to watershed area as measured by the ALSC, and to watershed areas in the Oswegatchie and Black basins generated from new 10 meter 1:24000 scale DEMs as described above.

Temperature and Precipitation

Ollinger et al. (1993) used records from National Oceanic and Aeronautics Administration weather stations in New England, NewYork, New Jersey, and Pennsylvania from between 1950 and 1981 to build a statistical model of temperature and precipitation for the Northeast by regressing monthly means of precipitation and temperature against latitude, longitude, and elevation. Regression coefficients for maximum and minimum temperatures from their model were as expected for the Northeast region: colder to the north and east. The rate of

change of temperature with altitude was close to the accepted average environmental lapse rate of 6.5 ^{o}C per 1000 meters of elevation (Lydolph 1985). Coefficients for precipitation decreased to the north and west, and increased with elevation reflecting orographic effects on rainfall.

Coefficients from Ollinger et al. (1993) were used to estimate monthly mean temperature and precipitation for the Adirondacks using the 10 meter DEM's supplied by NYS DEC as the source of latitude, longitude, and elevation information. For each watershed, the appropriate DEMs were joined, and the area of the watershed clipped from the joined grids (see Appendix 10 for Arc-Info aml macro program). Longitude and latitude grids were created by converting the DEMs into a point data model, adding the x and y coordinates to the points, and converting the x and y coordinates back into grids. New temperature and precipitation grids were calculated by

$$\text{valgrid} = C + B_{elev} * \text{elevgrid} - B_x * \text{longgrid} + B_y * \text{latgrid}$$

where C = a constant, elevgrid, longgrid, and latgrid are grids of elevation, longitude, and latitude respectively, and B_{elev}, B_x, and B_y are coefficients from Ollinger et al. (1993). The mean of all the cells in the watershed was used as the mean monthly value for that watershed, and was written to a text file.

Yearly total precipitation for the OB and UH watersheds as calculated by this process is shown in Figure 10. The pattern of predicted precipitation is similar to what would be expected on theoretical grounds and from field information: precipitation increases in the high peaks and other areas with elevation, and increases from west to east. Actual long-term weather station data were not available at the APA at the time of this work with which to compare the results.

Runoff Estimation

Output from the Ollinger model was used as input to the Thornthwaite et al. (1944) evapotranspiration model. The Thornthwaite model relies on a monthly heat index based on empirical measurements. For months in which the mean temperature was below freezing, no evapotranspiration occurred. For months in which the mean temperature was above freezing

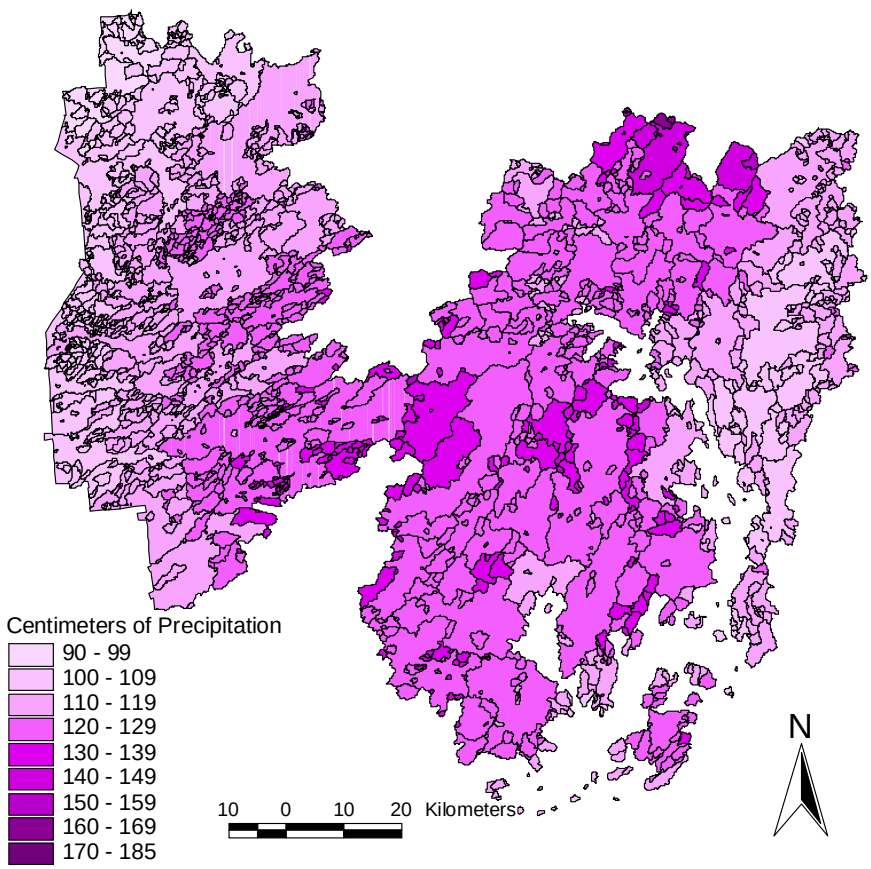


Figure 10. Spatial Distribution of Precipitation as Predicted for the Oswegatchie, Black and Upper Hudson Watersheds. Precipitation for blank areas in the Upper Hudson were not calculated.

evapotranspiration occurred as

$$E_m = 1.6 \left(\frac{10\ t}{TE} \right)^a \quad ,$$

where **E** = monthly evapotranspiration for month **m**, **t** = monthly mean temperature, **TE** = Thornthwaite's temperature-efficiency index (***i***), which is equal to

$$i = \sum_{1}^{12} \left(t/5\right)^{1.514} \quad ,$$

and ***a*** is equal to

$$a = 0.000000675(\mathrm{TE})^3 - 0.0000771(\mathrm{TE})^2 + 0.01792(\mathrm{TE}) + 0.49239 \ .$$

E was calculated for each month for each watershed using the mean monthly temperature calculated above. Runoff was calculated as surplus precipitation by subtracting $\mathbf{E_m}$ from monthly precipitation ($\mathbf{P_m}$) for each month. Where $\mathbf{E_m}$ was greater than $\mathbf{P_m}$, there was a moisture deficit, and water was withdrawn from a 4 cm soil moisture reservoir. Where $\mathbf{P_m}$ was greater than $\mathbf{E_m}$, and the soil moisture reservoir moisture was not full, moisture was returned to the reservoir, and surplus precipitation was correspondingly reduced. Runoff for the watershed was calculated by summing surplus precipitation over the year. For watersheds that contained tributary watersheds, runoff was calculated by summing the runoff weighted by watershed area for each local subwatershed polygon in the larger regional watershed.

New runoff was compared to the ALSC runoff estimate. The ALSC estimates of runoff were obtained from a map of mean annual runoff isopleths (Figure D-2 in ALSC 1985) based on runoff data from 1950 to 1980, the same years used in the Ollinger et al. (1993) study. The value of the nearest isopleth was assigned as the likely estimate of runoff for each watershed. The low variation in the ALSC runoff estimates (Figure 11) reflects the fact that the runoff map used to generate estimates of runoff only contains 3 isopleths (25, 30 and 35 inches of runoff). Comparison of the Ollinger-Thornthwaite (OT) estimates of runoff with the original ALSC runoff estimates shows that the general shift of values in the runoff estimates is similar.

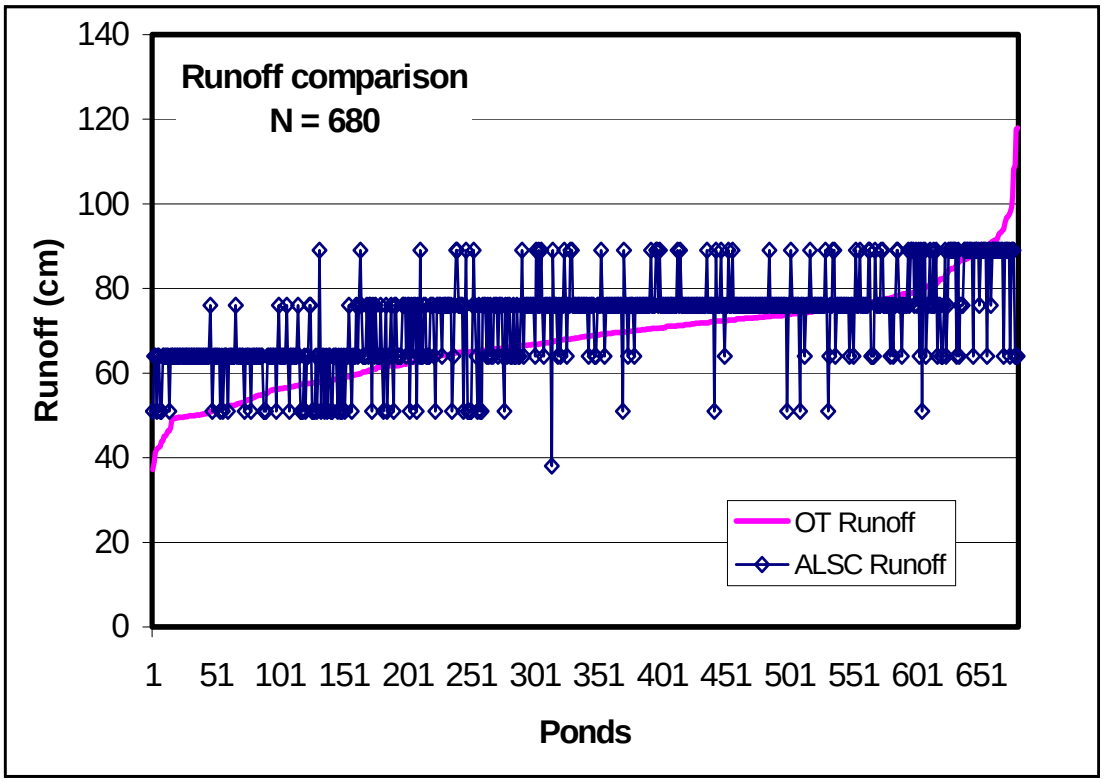


Figure 11. Comparison of Runoff Values in the ALSC Database and Estimated New Runoff as Described in the Text. Ponds were ordered by size of the new runoff estimates. Estimates produced for this study are referred to as OT. These are compared to estimates produced by the Adirondack Lakes Survey Corporation (ALSC) in the 1980's.

The new runoff data were also compared to actual runoff values from existing USGS discharge values from gaging stations in the Adirondack Park. Latitude and longitude location of each long-term stream gaging station was obtained from USGS (see http://waterdata.usgs.gov/nwis-w/NY/ for USGS gaging station data from New York). Long-term discharge for these stations was obtained from Bloomfield and Sutherland (1989). They included any station in the Adirondacks that was active at the time of their study that had at least a 15 year period of record. No attempt was made to select a fixed time period that corresponded to the records used in the ALSC and OT runoff studies.

Gaging station locations were plotted as points over the OT runoff estimates (Figure 12). Modeled runoff agreed with the gaging stations to the west (in the Oswegatchie/Black) better than to the east (in the Upper Hudson). In the OB, modeled runoff was 2 to 5 centimeters higher than the gaging stations. In the UH, modeled runoff was from 10 to 12 centimeters higher than the gaging station data.

There are several potential explanations for this difference. Winter records are generally considered by USGS to be poor, with the potential for up to 20% error (Bloomfield and Sutherland 1989). The differences observed here are less than 20%. The Ollinger model coefficients were estimated using data from the whole of the northeast, and do not completely reflect Adirondack conditions. In addition, the Ollinger coefficients do not include the possibility of a "rain shadow," which is an important factor in the Adirondacks, and may have resulted in overestimation of precipitation and runoff on east facing slopes in the UH. The Thornthwaite moisture model was developed for use in agricultural conditions, and may underestimate evapotranspiration under forested conditions. Lastly, Bloomfield and Sutherland (1989) included all stations that were active at the time of their study with at least a fifteen-year period of record. This introduces the implicit assumption that there are no time trends in stream discharge in the gaging station records that they chose to include. Examination of the gaging station records for the Sacandaga River near Hadley shows that there was a period of low stream discharge in the 1960's (Figure 13). This could introduce a bias towards low long-term discharge into the stream discharge records that they report in their study.

Flushing Rate Calculation

New flushing rates were calculated using the existing ALSC measured lake volumes and runoff, watershed areas from the OB and UH projects, and runoff calculated using the procedure described above. Appendix 14 contains the original ALSC flushing rates calculated in the 1980's and new flushing rates calculated using the OT estimates organized by DEC pond number. Differences between the ALSC and OT flushing rates reflect both the effect of the two different runoff estimates and the new watershed areas used in the OT calculations.

Uses and Further Research

The differences between the ALSC and OT runoff measurements, up to 10 centimeters per year for many watersheds, and larger at higher runoff values, is significant from a lake

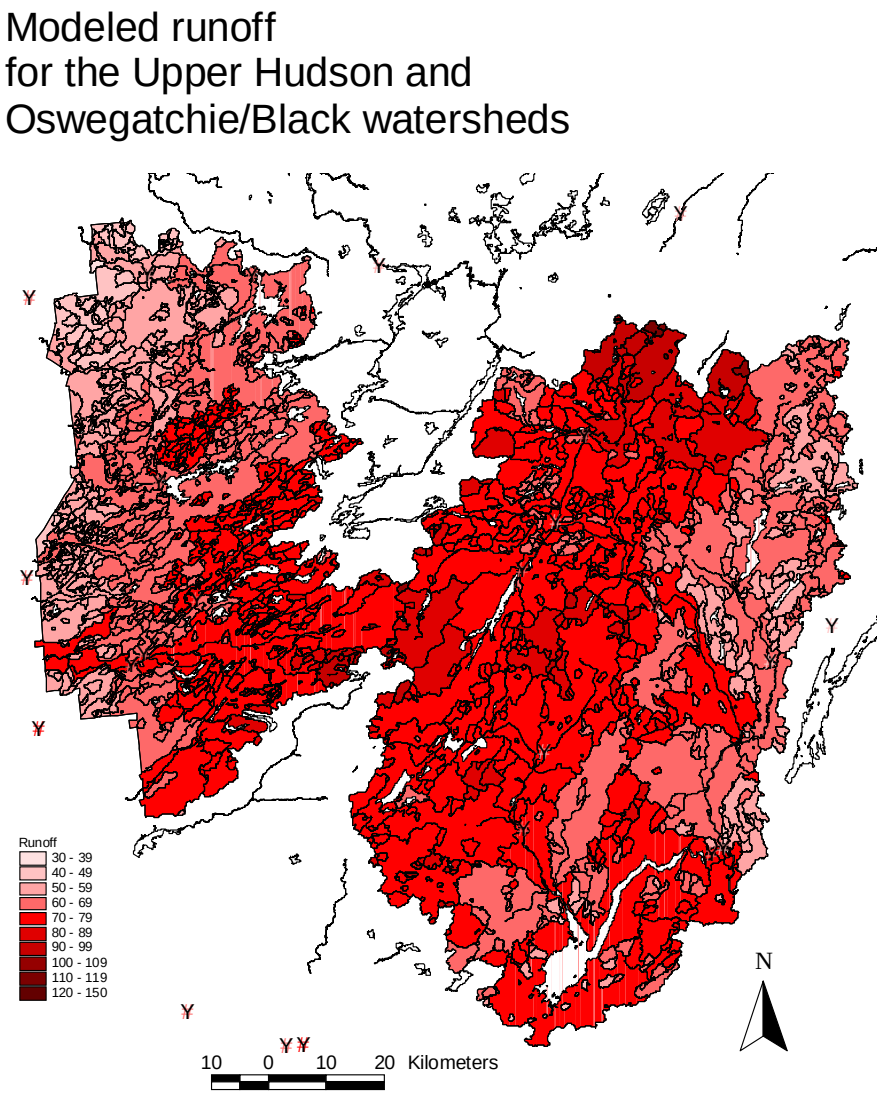


Figure 12. Modeled Runoff for the Upper Hudson, Oswegatchie, and Black Watersheds. Dots show the location of USGS gaging stations in the region. Gaging stations and runoff use the same scale. Differences between runoff estimates and USGS gaging stations occurred in those locations where the dot representing the gaging station was a different color than the color of the polygon over which it occurred.

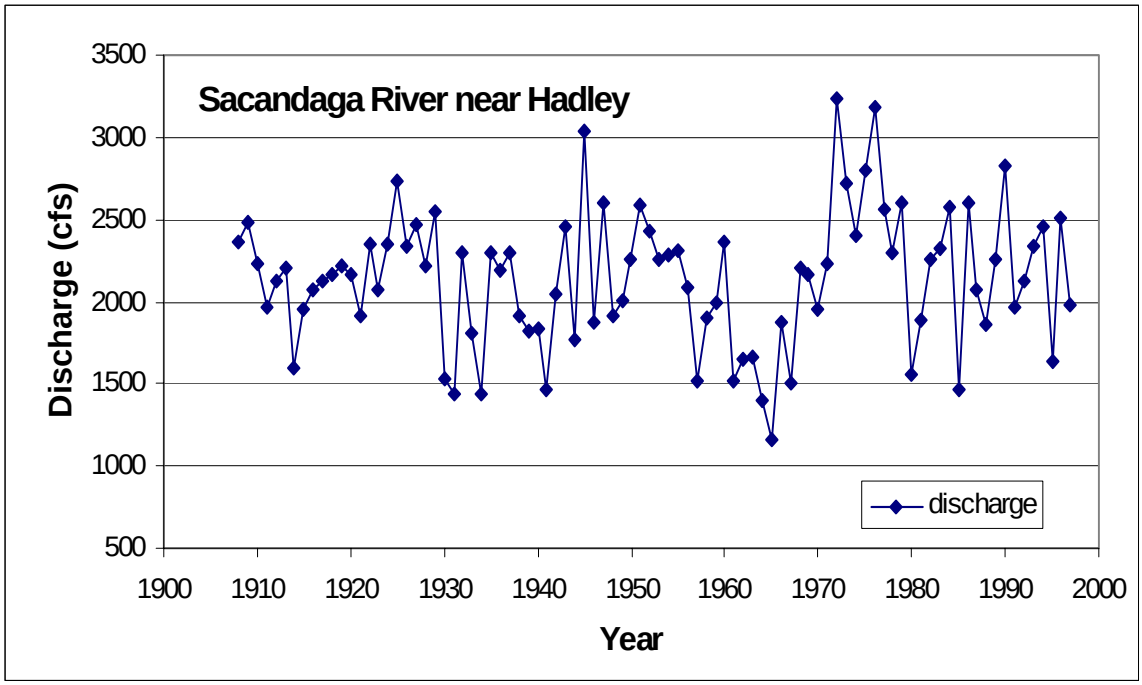


Figure 13. Historical Discharge from the USGS Gaging Station in the Sacandaga River near Hadley, New York (USGS Station Number 1325000). Note that discharge between 1960 and 1975 is lower than before 1960 and after 1980.

management perspective. This difference reflects the coarse methods used to calculate the original ALSC runoff estimates. Runoff and watershed area are important factors in determining flushing rate and lake sensitivity to changes in inputs of nutrients. New flushing rates were used to calculate lake sensitivity to nutrient inputs, as described below. Runoff and flushing rate estimates from this work will be added to the ALSC database for those watersheds for which ALSC has collected data.

A significant improvement in the modeling process would be to estimate new coefficients for Ollinger style models using only Adirondack and near Adirondack data. Since the Ollinger et al. (1993) models are based on weather data from the entire northeast, they incorporate the major factors in shaping weather over the entire region. Local factors that influence temperature and precipitation in the Adirondacks, such as rain shadow on the eastern side of the High Peaks, are not included. Most existing weather stations in the Adirondacks are below 600 meters, which does not capture the estimated 22% of the area of the Park above that elevation. Additional high

altitude stations, or other weather data, would significantly improve confidence and of an Ollinger-type model specifically for the Adirondacks.

Tax Parcel Centroids for Warren County

The New York State Office of Real Property Services (ORPS) collects tax parcel information from the counties within the State and makes it available to the Park Agency. These data contain the location of the center of the parcel (the parcel centroid), the tax property classification of the parcel, information on the date of last construction on the parcel, parcel identification number, tax property class, and other information about the parcel. The coordinates of the center of the tax parcel were used to create a map of the parcel centroids as points for use in the Agency Lookup System. The Agency's data were last updated in 1998, and historical tax parcel centroid data are available at the Agency as far back as 1989. ORPS tax parcel data are available for every county in the park except Warren County.

There are no official digital tax parcel data available for Warren County, although preliminary digital tax parcel data recently have been made available to the Park Agency. Warren County is in the process of preparing official digital tax parcel maps which will be available in 2001. The preliminary data made available by Warren County, and used in this study, includes property class information with centroid coordinates. The probable date of origin for the data is 1996, but may vary depending on the town or village.

Both the ORPS and Warren County data were examined to remove extraneous and incomplete data entries. Data were obtained as DBF format files. These were sorted to remove parcel information that did not include the X and Y coordinate information necessary to locate the parcel centroid on the map. The remainder were converted into GIS point coverages in Arc-Info using the DBFARC command. Some of the resulting points were outside the geographic boundary of the source county, and were removed from the data set. Most of the removed data represented easements, however, some represented residential development for which parcel centroid coordinates were not available. These errors and omissions in the tax records are unfortunate but unavoidable given the large number of individuals involved in recording and maintaining the data. When interpreting these data it should be kept in mind that some parcel centroids were not included, and the reported parcel number or parcel density are underestimates of the true values. These data were used to examine historical trends in development and to evaluate the density of development on privately held land in different land use categories according to the Adirondack Park Land Use and Development Act Plan, as described below.

Cumulative Impacts

Introduction

Cumulative impacts result when separate impact events occur close enough physically so that they overlap in space and/or time such that the target natural system does not have time to recover from previous impacts. Changes that result from each individual impact are often small and accumulate over time so that it is difficult to pinpoint exactly when or how much a natural system has changed. Changes may include the gradual the gradual consumption of area through nibbling around the edge, or change in the function of natural areas as when the chemical properties of soils are altered by atmospheric deposition. A major goal of this project was to find methods by which the data described above can be used to improve the ability of the Park Agency to protect the resources of the Park from cumulative impacts. We used four approaches to describe cumulative impacts depending on the type and availability of data: realized impacts, inferred impacts, potential impacts, and anticipated impacts. The previous sections describe the data gathered specifically for this project and data obtained from other sources and previous projects. Further sections describe efforts to compare the different data layers to confirm the validity of the layers and to test the ability of the layers to reproduce predictions made in other studies. This section describes approaches to use the assembled information to improve understanding of cumulative impacts in the Park and to use the data to improve protection of the resources from cumulative impacts by discussing the data currently available or desired for each approach.

Realized impacts

Realized impacts are those that have already happened, and can be linked directly to a cause through observation. Many cumulative impacts occur as the result of repeated impacts that occur over time. In order to describe these types of impacts it is necessary to have a series of observations describing the impacted system and activity or activities that can be reasonably linked to observed ongoing impacts. For example, photographs of alpine meadow vegetation taken at intervals over several decades, clearly show that visitors to the High Peaks have impacted the vegetation by treading on it. Early photographs show that the alpine vegetation originally covered a larger area than today. Current photographs show much less vegetation, particularly near established trails. The presence of the time series of photographs demonstrates

the changes in the vegetation extent. This is a cumulative impact since it occurred over a long period of time, and is the result of many people walking on the vegetation. Since the number of visitors to the High Peaks is increasing, this impact should be expected to continue.

Periodic monitoring provides the best tool for identifying realized impacts. Unfortunately, existing data rarely provide more than a single snapshot in time. While the lake chemistry data collected by the Adirondack Lakes Survey Corporation in the 1980's is important and useful documentation of the chemical state of lakes in the Park at the time, changes in atmospheric deposition and development patterns over the 15 years since then will progressively limit its value as a description of current lake chemistry. On the other hand, repeated collection of lake chemistry data over a similar large region, at regular intervals, using the same lakes or a more representative set of lakes, would provide an invaluable tool for testing the effect of changes in atmospheric deposition on the watershed of these lakes, improve understanding of the biogeochemistry of these watersheds, allow better identification of the effects of development on the watersheds, and improve the ability of the Agency to identify landscapes that are sensitive to impacts from development and those that are insensitive to development impacts. Barring the collection of baseline time series, the presence of impacts and their causes must be discovered using other methods.

The realized impacts approach requires that enough data be available to directly link the cause to the impact. From a management perspective, it is usually neither possible, nor desirable, to wait until an impact has been linked directly to a cause through observation alone, to act to prevent damage to a resource. In fact it may be desirable to anticipate impacts to especially sensitive systems by searching for a) locations where there is high impact potential, and b) for concentrations of activities that lead may to impacts. In addition, simply knowing that a change has occurred is often not enough to understand the cause of the change. Even when it is clear that some change has happened in a particular natural resource, there may not be enough observations to clearly identify the cause of change. In some instances there may be many potential causes about which there is little information so that the cause of the change cannot be immediately ascertained. For example, it is clear that the fish assemblages in many Adirondack lakes are sensitive to acidic deposition. Indeed, fish populations in many lakes have disappeared or changed completely. As efforts to curb acid precipitation continue, there is growing interest in

whether reductions in sulfur emissions have resulted in improvement in fish assemblages. In the meantime several things may have happened in the lake that make it difficult to ascribe observed changes in the fish assemblage to the reduction in sulfur deposition. These may include the intentional or unintentional introduction of new species of fish, development of homes along the margin of the lake, or the invasion of beaver in parts of the watershed. Hence, the effect of reductions in sulfur deposition on the original fish biota of acid-affected lakes cannot be determined easily for any given lake by direct observation. Instead, it is necessary to examine many lakes that were similarly impacted by sulfur deposition, and what has happened to each of them as sulfur emissions were reduced taking these other factors into account. In these cases, it is necessary to use other approaches to link impacts with causes and anticipate the occurrence of impacts.

Inferred Impacts

Inferred impacts are those that are found by a process of data-based inference. The model utilized in this process must include a description of the linkages between activities that might be expected to result in impact and natural resource inventory. Inferred impacts are found by comparing the structure and function of natural systems that are similar except for the activity that is potentially causing impact. This approach involves constructing conceptual, statistical, or other kinds of models of the environment that include human activities as an independent variable in the model. A drawback of this approach is that a large amount of detailed data are required in order for the model to be quantitative and reasonably accurate in predicting impacts.

Data are available for constructing these models for the Adirondack Park, partly as a result of this and the previous project in the Oswegatchie and Black (OB) watersheds (Roy et al. 1997). The Adirondack Lakes Survey Corporation (ALSC) collected lake chemistry data for 1497 Adirondack Lakes in the mid 1980's (Baker et al. 1990). This project and the OB project have collected wetland, watershed, and other map data layers for the Park. Further collection of wetland and watershed data layers continues in the drainages leading to the St. Lawrence River. Other digital map data existed at the Agency (soil, bedrock and surface geology, tax parcel information), or was made available during the project (10 meter DEMs). These data are currently being used to construct a distributed geographic multivariate statistical model to explain the distribution of dissolved organic carbon (DOC) in ALSC lakes located in the Upper

Hudson, Oswegatchie, and Black River watersheds. If the model is successful, a reasonable extension would be to construct a similar model for phosphorus, an important nutrient in lakes.

Potential impacts

Potential impacts are those that are likely to happen because of a high concentration of activities that lead to impact. One way to identify potential impacts is to examine the proximity of activities that might lead to impacts, even in the absence of direct demonstration of impacts. This approach overlays the location of activities that are known to cause impact with the location of resources that might be impacted to identify resources that may require more careful monitoring and protection. An example of this approach is to use tax map parcel centroids to locate areas where impacts from development activities might be associated with wetlands and waterbodies in the park.

Anticipated impacts

Anticipated impacts are those that are likely to happen based on a knowledge of the sensitivity of the potentially impacted resource. This approach is used where there is information on the structure and function of a resource, but no or insufficient data on the impacts occurring to the resource. Natural ecosystems vary in sensitivity to impact depending on the location and characteristics of the ecosystem. For instance, lakes with high flushing rate are less sensitive to nutrient inputs than lakes with longer retention times. The anticipated impact approach is used to develop a procedure to identify lakes that may be sensitive to nutrient inputs.

It is not possible to use any single cumulative impact assessment strategy exclusively for any cumulative impact assessment protocol. Ideally, it would be desirable to know exactly what the consequences of any decision regarding protection of natural resources will be. Practically, it is necessary to use models where appropriate data exist. Where data does exist, it will be necessary to identify sensitive resources and high concentrations of impact activities. As information on the location and character of impact activity and resources improves, the understanding and anticipation of impacts will improve as policy adapts to the development of new knowledge and understanding. This requires the continued collection and improvement of baseline data and the adaptation of resource protection strategies to the evolving information. The following sections contain illustrations of these approaches using the data that is currently available at the Adirondack Park Agency.

Tax Parcel Centroids

One of the few available measures of direct human impact on the landscape in the Park is the number and location of buildings and other development activities. Most Park residences outside the large incorporated municipalities use septic systems for sewage treatment/disposal. Septic systems are a potential source of nutrients (phosphorus and nitrogen) to aquatic systems. Residential development involves the construction of roads and buildings which act as impervious surfaces, changing drainage and increasing the rate and quantity of nutrient runoff to the environment. Buildings and roads also affect the use of natural habitat by wildlife by changing movement patterns, changing the availability of food resources, fragmenting large areas of contiguous habitats into smaller sections, and providing corridors for the movement of exotic species. This section uses parcel centroids in a preliminary assessment of potential effects from land use activities.

Ideally, the actual location and nature of the development activity should be known in order to document the location of an impact. Some effects from development activities on the structure and function of ecosystems are located downslope with little or no direct impact. Nearly all impacts can be expected to decrease with distance. The best currently available information on the location of development activities involving buildings is the Office of Real Property Services (ORPS) tax parcel database. The database also contains information on the general type of activity (residential, commercial, or public service) occurring on the parcel. Unfortunately, the tax parcel database includes the coordinates of the geographic center of the parcel, otherwise known as the parcel centroid, not the actual location of the development activity on the parcel. Because some parcel data is incomplete (many parcel records do not contain locations), and more recent activity is not always included, the tax parcel data is at best, an underestimate of the true occupation intensity. For impact assessment purposes, tax parcel data should be interpreted as the minimum potential impact, not actual amount of impact.

Parcel centroid data can be used in several ways to examine existing and potential human impacts. Overlaying a map of parcel centroid locations on other digital resource and land use classification maps can be used to identify where high concentrations of development exist in relation to fragile resources. The location of a high density of parcel centroids in relation to the estimated capacity of the land can be used to raise a warning where further parcels are being

added. Because parcel centroid data are available for several different years, a time series can be constructed to assess regional trends in development and anticipate areas where future development is likely to occur.

This section uses tax parcel information to 1) compare the location of residential tax parcel centroids using a time series of parcel centroid data from 1989 and 1999, and 2) estimate the saturation of land units classified as moderate, low, rural, and resource management on the Adirondack Park Land Use and Development map. Saturation is defined as the number of existing parcels (not including parcels with vacant and forest tax classifications) divided by the potential number of parcels (maximum buildout) as defined by the APLUDP.

Time Series Comparison of 1989 and 1998 Tax Parcel Centroids

Tax parcel centroids from the years 1989 and 1998 were used to examine trends in the location of residential parcels over time for 11 out of the 12 counties in the Park (Warren county is not available). A residential parcel is one occupied with a seasonal or permanent single family dwelling, including mobile homes.

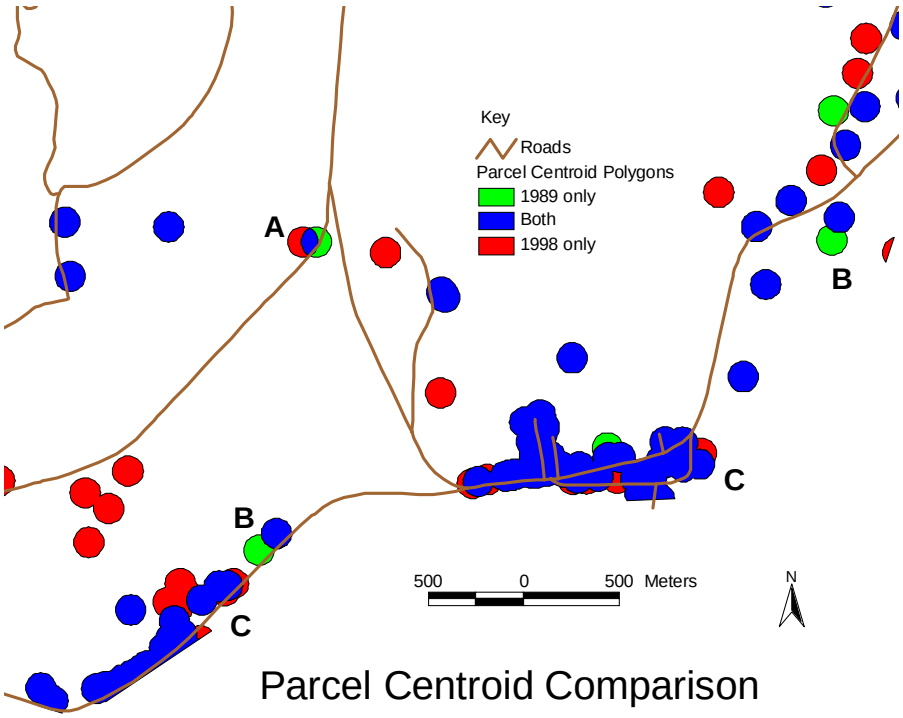
The 1989 and 1998 tax parcel centroids were used to create a map of residential areas similar to the one created in Roy et al. (1997). Circular buffer polygons were created around each residential parcel centroid. The size of the buffer polygon (2.0 Ha, or ~5 acres) was chosen to insure that parcels around lake shores could be identified by intersecting the buffered polygons with a map of lakes and ponds. Two or more parcel centroids less than 161 meters (500 feet) apart resulted in the creation of a larger polygon. All polygons resulting from residential parcel centroids were retained in the final map.

Tax data for 1998 were obtained as DBF format files for every available county. These were sorted to remove parcel information that did not include the location of the parcel centroid. The remaining parcel data were converted into point maps using Arc-Info. Some points fell outside the boundary of the source county, and were removed. Most of the removed data represented easements, however, some residential parcel centroids were also removed. These errors and omissions in the tax records are unavoidable given the large number of individuals involved in recording and maintaining the data and the number of points involved. Interpretations made with these data should recognize that some parcel centroids were not included, and reported parcel number and parcel densities are underestimates of the true values. A second map

of residential areas was then prepared for 1998 using the same methods as described for the 1989 residential areas map.

The residential area maps for 1989 and 1998 were overlaid. Areas present in both, only in the 1989 map, and only in the 1998 map were identified. Areas in the 1998 map that were not present in the 1989 map were interpreted as new development. Some areas were present in the 1989 map that were not present in the 1998 map. These may be due to (1) changes in the location of the parcel centroid when the parcel was subdivided (see **A** in Figure 14) which resulted in changes in the location of the buffer polygon, (2) changes in the classification of the parcel from residential to some other use, or (3) missing coordinate information on the points used to create

Figure 14. Time Series of Tax Parcel Centroids for Ausable Forks, New York. **A** indicates the location of a parcel centroid that probably changed location between the two time periods. The green area near **B** is the location of a centroid that was present in 1989 but not in 1998 either because it changed classification in the intervening period, or was missing from the 1998 data. The red areas near **C** show nibbling along the edge of previous settlements.



the 1998 parcel map (see **B** in Figure 14). Field investigation of the region shown in Figure 14 showed that some of these parcels were converted to commercial use.

The overlay map was summarized by county and size of the buffer polygon. Polygons were divided into six size classes: polygons less than the size of a single isolated parcel (2 hectares), polygons the size of a single isolated parcel centroid, polygons the size of small (between 2 and 10 hectares) and large (10-100 hectares) subdivisions, and the size of towns (greater than 100 hectares).

The area of the polygons present in each polygon size class, the number of polygons present in each size class, and the number of parcel centroids in these polygons were compared. The number of parcel centroids in the different polygon size classes gives an indication of the concentration of development activity, and the number of new centroids gives an indication of the rate of subdivision activity. While size of the buffer polygon was not chosen to reflect the area that is actually impacted by a project, the area in the buffer polygons is a measure of potential impact on the landscape. The number of polygons in each size class can be used to indicate the average size and number of parcels present in each size class.

Results

The polygons resulting from the overlay and buffer analysis can be divided into three categories based on size:

1) smaller than would be created by a buffer around a single isolated tax parcel
2) the size of a single tax parcel
3) larger than the size of a single tax parcel.

Small polygons (< 2 ha) from the overlay analysis come from several potential sources. Most small polygons in the overlay that came from the 1989 data were extremely small and were located around the margin of other larger polygons that contained a centroid from the 1989 and 1998 (Table 10; 117.54 ha). These are probably the result of rounding error by the computer in calculating the boundary of the buffer polygons. Small polygons in the difference data were individually larger in size, and obviously the consequence of new development (Table 10: 3261.70 ha). These primarily represent nibbling from new development along the outer edge of existing development (see areas marked **C** in Figure 14). These polygons are a measure of the extension of towns and other concentrations of development into new areas. Assuming that all of

	County	< 2 Ha	Singles	2-10 Ha	10-100 Ha	> 100 Ha	Total
1989	Clinton	16.60	1880.85	1397.24	1364.30	307.32	4966.35
	Essex	14.60	5287.56	3608.92	4915.80	3437.27	17264.15
	Franklin	24.97	1866.82	1440.30	1932.84	830.36	6095.29
	Fulton	14.28	1457.63	1157.29	2121.88	902.43	5653.52
	Hamilton	0.34	1363.11	1396.93	2481.82	685.59	5927.80
	Herkimer	10.78	935.93	861.59	1265.08	736.82	3810.20
	Lewis	5.46	404.68	285.01	576.04	0.00	1271.19
	Oneida	0.00	46.25	71.19	206.26	110.19	433.88
	Saratoga	6.29	926.45	724.11	1412.68	583.11	3652.64
	St. Lawrence	8.74	1101.26	635.52	930.46	314.66	2990.63
	Washington	15.45	616.27	518.13	670.37	112.02	1932.25
	Total	117.54	15886.81	12096.24	17877.53	8019.78	53997.91
Increase in 1998	Clinton	311.36	645.54	266.13	40.17	0.00	1273.21
	Essex	1012.38	1389.25	591.99	42.13	0.00	3035.75
	Franklin	342.98	685.47	315.98	56.76	0.00	1399.19
	Fulton	254.13	362.22	186.25	0.00	0.00	902.60
	Hamilton	360.53	362.87	218.07	12.92	0.00	954.38
	Herkimer	225.52	352.85	90.71	19.46	0.00	688.53
	Lewis	89.11	129.07	76.18	0.00	0.00	294.36
	Oneida	28.32	20.15	8.29	0.00	0.00	56.75
	Saratoga	210.43	282.34	167.99	11.06	0.00	672.83
	St. Lawrence	126.49	306.61	51.96	0.00	0.00	485.07
	Washington	196.44	288.29	103.90	0.00	0.00	588.63
	Total	3261.70	4824.65	2077.46	182.50	0.00	10351.30

Table 10. Change in Polygon Area Using 2 Hectare (~5 Acre) Buffer Polygons Around Tax Parcel Centroids for the Years 1989 and 1998. The 1989 areas were subtracted from the 1998 areas using ARC-Info and the resulting polygons organized by size. See text for explanation of the polygon size classes.

these represent additions to preexisting towns and subdivisions, there was an 8.5 percent increase over 9 years in the buffer area of residential parcels in towns over 9 years.

There were 58203 residential parcel centroids present in the eleven counties included in the analysis in 1989 (Table 11), and 5823 new residential parcels were created between 1989 and 1998, an increase of approximately 10 percent in 9 years.

The number of new single parcel polygons is a measure of the rate at which development is extending into the private open space areas. Parcel centroids on which these polygons are based are more than 500 feet from the next nearest parcel centroid. One third as many new isolated parcels were created in the period between 1989 and 1998 as were present in 1989

(Table 11). Greater than 750 new isolated parcels occurred in Essex County which contains the High Peaks, one of the more popular tourist regions in the Park. Other counties in which more than 300 new isolated residential parcels were created inside the Park include Clinton and Franklin counties.

The larger polygons (2-10, 10-100, and >100 ha) in the 1989 data represent subdivisions, villages, and other associations of parcels. Larger polygons in the difference data may or may not be attached to preexisting developed areas. The 1989 data represents the number of these settlements present at the time. It is clear from this that Essex county contains more communities and subdivisions than any other county included in the study (Table 12), and that more new subdivisions and residential parcels were created in Essex County than any other county.

	COUNTY	< 2 Ha	Singles	2-10 Ha	10-100 Ha	> 100 Ha	Total
1989	Clinton	8	869	971	1880	918	4646
	Essex	5	2175	2315	5881	7295	17671
	Franklin	13	1003	1084	2435	2926	7461
	Fulton	8	637	869	3100	2042	6656
	Hamilton	0	644	1061	3126	1101	5932
	Herkimer	7	423	624	1451	1727	4232
	Lewis	2	187	195	799	0	1183
	Oneida	0	23	63	368	280	734
	Saratoga	3	434	528	2178	1660	4803
	St. Lawrence	5	487	492	1275	580	2839
	Washington	7	258	366	1075	160	1866
	Total	58	7140	8568	23568	18689	58023
Increase in 1998	Clinton	146	323	184	44	0	697
	Essex	548	783	448	75	0	1854
	Franklin	156	355	216	64	0	791
	Fulton	177	181	127	0	0	485
	Hamilton	178	181	201	9	0	569
	Herkimer	110	179	63	16	0	368
	Lewis	46	65	55	0	0	166
	Oneida	13	10	7	0	0	30
	Saratoga	83	142	112	8	0	345
	St. Lawrence	50	155	32	0	0	237
	Washington	76	143	62	0	0	281
	Total	1583	2517	1507	216	0	5823

Table 11. Number of Residential Class Parcel Centroids in the 1989 Real Property Services Data and New Parcel Centroids in the 1998 Data by County and Polygon Size.

Discussion

We developed a map from which the s in this section can be examined to identify where concentrations of new development are occurring (Figure 15). Although the data were presented at the scale of counties, it easily could be extracted at the scale of towns, watersheds, or any other spatial scale, so long as a map of these units exists in digital form.

The data at the county level suggest that residential parcels increased by 10 percent over the 9 years between 1989 and 1998, and that 40 percent of the new parcels were at least 500 feet apart. This may be because of the minimum lot size required for some land use areas, but also suggests that development continues to be extended into the open areas of the Park.

The time series map also can be examined to find out how the pattern of new

	COUNTY	2-10 Ha	10-100 Ha	> 100 Ha	Total
1989	Clinton	291	55	2	1301
	Essex	751	207	19	3613
	Franklin	303	86	3	1337
	Fulton	237	80	4	1060
	Hamilton	277	107	5	1067
	Herkimer	173	62	3	709
	Lewis	61	23	0	288
	Oneida	13	6	1	43
	Saratoga	150	51	4	673
	St. Lawrence	133	35	2	725
	Washington	108	21	1	448
	Total	2497	733	44	11264
Increase in 1998	Clinton	72	3	0	773
	Essex	172	3	0	2203
	Franklin	89	4	0	911
	Fulton	55	0	0	733
	Hamilton	65	1	0	778
	Herkimer	27	1	0	531
	Lewis	21	0	0	195
	Oneida	2	0	0	55
	Saratoga	45	1	0	538
	St. Lawrence	14	0	0	372
	Washington	31	0	0	460
	Total	593	13	0	7559

Table 12. Number of Polygons That Contributed to the Area Reported in 10 for the Larger than Single Size Polygons.

development compares to what already existed. Cursory examination of the map suggests that new settlement is filling in vacant spaces along roads (see **A** in Figure 15). This suggests that impacts to the aesthetic quality of the driving experience will increase where roadside lots are being developed.

The buffer approach can be used to examine what is happening in the neighborhood of developed areas, or resources that have been mapped digitally. The time series map (see Figure 15 for a section of this map) was created using a 161 meter, or 500 foot diameter buffer polygon to identify parcel centroids that were probably associated with lake front parcels in 1989. However, a 500 foot diameter buffer is not necessarily the most appropriate buffer for some types

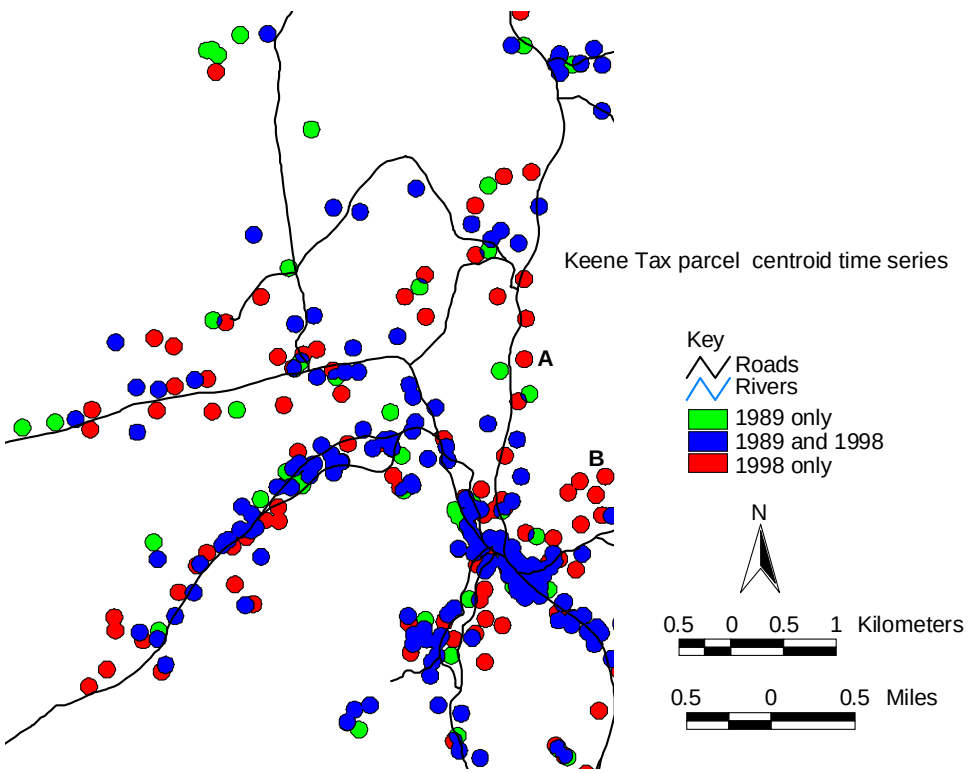


Figure 15. Time Series of Tax Parcel Centroids for Keene Valley. **A** indicates parcels filling in along previously vacant areas along roadsides. **B** indicates a small subdivision in which parcels are widely spaced.

of impacts (road crossing over streams) or some types of resources (heron nesting colonies). A buffer analysis could be conducted to discover the number of parcel centroids or the length of roads near wetlands in general or wetlands of a particular type at several distances.

Parcel Saturation

One measure of potential impact is the number of developed parcels present in a political or ecological unit versus the maximum number allowed under current land use regulation. The term "parcel saturation" is used to describe this measure. This section describes the creation of a saturation map of land in private ownership organized by Adirondack Park land use classification and municipal or watershed boundaries.

The Adirondack Park Land Use and Development Plan map (APLUDP) is the foundation of resource protection in the Park on private lands. It establishes 15 categories of land classification for public and private lands. State lands are divided into Wilderness, Wild Forest, State Administrative, Intensive Use, Primitive, Canoe Area, Historic, Pending Classification, and Open Water depending on management objectives. Active development on State Lands is limited to a few intensive use areas. Overall, the lands are managed in their natural state for the enjoyment of the public. Private lands are divided into Hamlet, Moderate Intensity, Low Intensity, Rural Use, Resource Management, and Industrial. Development is allowed on land in private ownership with certain restrictions on the density of development (Table 13). The density restrictions were based on estimates of the carrying capacity of the land, and of the capacity of the land to withstand development impacts (Daniels 1972, Davis 1975).

This section compares the number of existing buildings according to the 1998 tax parcel data, and the maximum number allowed according to the APLUDP map for the 105 towns and

Land use classification	Buildings allowed per square mile	Acres per building
Hamlet	Local restriction	
Moderate Intensity	500	1.3
Low Intensity	200	3.2
Rural Use	75	8.5
Resource Management	15	42.7
Industrial Use	No intensity restriction	

Table 13. Overall Intensity Guidelines for Private Land Classifications as Described in the APA Act

municipalities in the Park. It also examines parcel saturation levels for the watersheds delineated for the Greater Upper Hudson Basin as part of this project and as part of the previous project in the Oswegatchie and Black River watersheds.

Method and Discussion

The number of parcels present in each town or village was obtained by overlaying a map of political boundaries on maps of tax parcel centroids and land use units using Arc-Info. Vacant (300 class property code) and forest (900 class property code) land were not included in the analysis because the impacts from these land uses were not equivalent to those from parcels that involve construction of buildings. The remaining points were divided into residential (200 class property code) and nonresidential (agriculture, commercial, recreation and entertainment, community services, industrial, and public services). The information from the overlay analysis was exported to a file and organized using Access and Excel. Tax parcel centroids were organized by the political unit and land cover class into which they fell.

Some parcel centroids fell into areas that were classified as part of the forest preserve (State Owned) and in lakes (Open Water). This occurred where there were small mismatches between the parcel and land use classification map layers, and indicates parcel centroids that are very close to the border between the forest preserve and private land. It is not clear which land use class these parcels belong in, but visual inspection showed that these points were usually near land classified as Hamlet, so they were included in this category.

The density restrictions applied by the APLUDP map were used to compute the maximum parcel capacity for land use classifications with a set parcel size for each town or village by dividing the area per parcel required by the area of the polygons in that land use classification. The area of towns and villages in each APLUDP land use classification was determined using the map overlays (Appendix 15). The same overlays were used to determine the number of tax parcel centroids in each APLUDP land use classification for each town (Appendix 15). The number of existing parcels in each town or village was divided by capacity to give an estimate of the saturation of that polygon (Appendix 17).

There is no density restriction for land classified as Hamlet in the Adirondack Park Land Use and Development Plan so a saturation value cannot be calculated for Hamlet polygons. Instead, the density of parcels on land classified as Hamlet was computed by dividing the number

of parcels present in Hamlet (Appendix 16) by the area in Hamlet for each town and village (Appendix 15).

Some towns with no area in Hamlet reported a few parcel centroids in Hamlet. These are probably the result of errors in the overlay of the GIS map layers. Some saturation calculations resulted in greater than 100 percent of the area available being reported as occupied (italics in Appendix 17). Most of these instances occurred where the area available in that land class for that town or village was very small, and may contain parcel centroids that represent parcels that cross land classification boundaries.

A more detailed version of these data was used to prepare a map of saturation and Hamlet density based on the individual polygons. For many towns and villages there was more than one polygon of each land use classification present. The more detailed map includes areas, number of parcel centroids present, saturation and density values for each polygon.

Conclusions and Recommendation

Private land was largely unsaturated, that is, for most areas the number of parcels present was far lower than the theoretical number allowed by land use regulation. Areas of high saturation were primarily in Resource Management and Moderate Intensity land use classifications. High saturation in Resource Management can be explained by the high minimum lot size required. High saturation occurred especially where development occurred along roads.

High saturation in Moderate Intensity areas was almost always along the shoreline of large water bodies. One of the insights this information gives Agency staff is that shoreline areas are being developed more quickly than other land use classification areas. This observation calls attention to the fact that there is little baseline information on the status of these waters with which to evaluate their sensitivity to impacts. These waters were omitted from the ALSC surveys in the 1980's.

Lake Sensitivity/ Vulnerability to Phosphorus Loading

Introduction

One of the goals of this project is to improve the ability of the Resource Assessment and Scientific Services (RASS) staff at the Agency to anticipate impacts to wetlands and water bodies in the Park. Currently, when large projects that may have an impact on the nutrient status of a lake are proposed, models of the effect of land use or nutrient addition on lake trophic status are used to test the impact of proposed development on lake chemistry. All potentially significant projects are evaluated using a screening model. Agency staff normally do not run more complex models because of restraints imposed by short project review clocks, and the time involved in gathering the required input data and setting up more complex models. This section applies several of the data layers gathered in this project to calculate the sensitivity of lakes to inputs of nutrients using Vollenweiders's Nutrient Budget Model (Vollenweider 1975) for subwatersheds in the Upper Hudson, Osewegatchie and Black watersheds that were sampled by the Adirondack Lakes Survey Corporation (ALSC) in the 1980's.

The response of a lake to input of nutrients from development or other sources depends on the rate at which nutrients are added to the lake, the original nutrient status of the lake, and the rate at which nutrients are flushed out of the lake. Because Adirondack soils are generally thin and unproductive, the climate is cold, and many headwater lakes are relatively deep, many Adirondack lakes have naturally low nutrient levels, are unproductive, and are potentially sensitive to nutrient inputs. Many Adirondack lakes are phosphorus limited.

Human and animal occupation can contribute significantly to the input of nutrients to lakes and wetlands in several ways. Most homes in the Adirondacks use septic systems for sewage treatment and disposal. Many of these are old, and all leak at least some nutrients into surface and groundwater. Homes are often surrounded by lawns that are fertilized. Homes and other buildings require roads, roofs, and other surfaces that speed the passage of water into aquatic systems. Although the population of the Park is only 130000 permanent residents, seasonal residents add an estimated 200000 people, concentrated during winter and summer tourist seasons. Residential areas are concentrated around and near lakes and waterways. The Park is also within a day's drive for 60 million people, who can easily visit on day trips and weekends. These represent an additional 9 million day and short-stay visitor entering the Park

annually. The presence of many low nutrient lakes makes the potential for cultural enrichment a concern even though the population density in the Adirondacks is relatively low.

The Adirondack Park Agency Act (New York State Executive Law, Article 27, section 805.4) mandates that the Adirondack Park Agency shall consider the effects of development on the natural resources of the Park in its decisions when considering any "significant new land use or development or subdivision of land in the Park." Natural resource considerations include "existing water quality," and "eutrophication," among others. The guidance document for planning and review of development projects (APA 1977), which is used by developers to design projects, states:

> Nutrient enrichment that might cause an increase in the natural rate of eutrophication should be avoided. Where potentially significant increases in the addition of nutrients to a water body may result from a project, the expected change should be calculated using the following or similar methods: ' A simple method for Predicting the Capacity of a Lake for Development based on Lake Trophic Status'(Dillon and Rigler 1975) and 'A Manual for Calculating the Capacity of a Lake for Development'(Dillon 1974 as cited in APA 1977). (APA 1977).

The APA Act mandates Agency staff to evaluate the potential for significant accelerated cultural eutrophication as a result of development activities that require an Agency permit. As a result, staff is interested in identifying vulnerable lakes before development is proposed in their watersheds, and in identifying lakes that are unlikely to change from the addition of nutrients. A second interest is to improve existing review methods to evaluate potential nutrient loading when developments are proposed in any watershed. Assessment of these lake eutrophication questions was begun in the previous EPA project by Roy et al. (1997).

The watershed model commonly used by RASS staff to make findings on the potential environmental impact of proposed development projects is LAKEMOD. Originally developed by the US Forest Service for the Lake Superior National Forest (Garn and Parrott 1977) in Minnesota, it was chosen by Agency staff because Lake Superior National forest is climatically and geologically similar to the Adirondack Park, and because the model can be run using existing lake data or data easily acquired by the project sponsor or Agency staff within the legal time constraints of project review. LAKEMOD is primarily used as a screening model to determine if

potential impacts are insignificant, or if more detailed data collection and modeling are recommended. Often, it is the only model used to make a quantitative determination of the number of new lots that can be allowed within a lake watershed.

LAKEMOD uses Carlson's Trophic State Index (TSI: Carlson 1977), and a lake sensitivity model built on Vollenweider's Nutrient Budget Model (Vollenweider 1975). Vollenweider's Nutrient Budget Model is used to identify mesotrophic lakes that are potentially sensitive to nutrient input changes. Mesotrophic lakes are those with intermediate levels of nutrients, and hence neither low productivity (oligotrophic) or high productivity (eutrophic) Additionally, LAKEMOD uses information on the landscape position of nutrient sources, to predict the potential effect of new development on the future trophic state of a lake. This study revisits LAKEMOD using the ALSC database to customize it to our needs.

The Adirondack Lakes Survey Corporation (ALSC) undertook a sampling program between 1984 and 1987 to document the effects of acid precipitation on Adirondack lakes. They collected chemical, physical, and biological information on nearly 1500 lakes. These lakes were selected by stratified random sampling of DEC numbered ponds within major watersheds in the Park (Baker et al. 1990). Every effort was made to select lakes without bias toward high or low productivity lakes. However, only lakes between 0.5 ha and 25 ha were included in the program. Some ponds were not sampled because they were remote, or were located on private land where landowners did not give permission for access. Thus, there may be some bias towards lakes that were in the forest preserve at the time, towards lakes that were easier to sample, and towards smaller lakes. Ponds were sampled in the Oswegatchie, Black, St. Lawrence, Lake Champlain, UH and Mohawk drainages during 1984 - 1987. There is no other comprehensive survey of lake chemistry for lakes in the Adirondack Park. Although collected over ten years ago, it is the best lake chemistry data currently available. The combination of ALSC limnological data and new and improved GIS data collected as a result of this project make it possible to investigate the use of standard limnological models to examine lakes in the Park for sensitivity to nutrient inputs, with the goal of identifying lakes that are more likely to be sensitive to nutrient inputs. These lakes will be flagged for special examination when projects in or near them are under review by the Agency.

The work reported in this section proceeded in two parts. First, values for Carlson's TSI were calculated using ALSC data for total phosphorus and Secchi disc depth. Second, Vollenwieder's sensitivity index was calculated, and the location of sensitive lakes was mapped. Calculating lake sensitivity required significant work estimating new annual runoff and flushing rate values, which was described earlier in this report.

Part 1: TSI(SD) and TSI(P) comparison

Carlson's TSI is a measure of the trophic state of a lake (Carlson 1977). Lakes with high phosphorus concentrations typically support high levels of phytoplankton and, consequently, have low light levels in the deeper waters. The index is designed on a scale from 1 to 100, and is calibrated so that each ten point increase in the index is the equivalent to doubling the biomass of algae in the epilimnion. Because they are related, Secchi depth, chlorophyll *a* and total phosphorus each can be used to calculate TSI values (Equations 1, 2, and 3). The best data to use in calculating TSI values are Chlorophyll *a*, since it is a direct measure of lake productivity.

1) $$\text{TSI (SD)} = 10\left(6 - \frac{\ln \text{SD}}{\ln 2}\right)$$

Equation 1

2) $$\text{TSI (Chl } a\text{)} = 10\left(6 - \frac{2.04 - 0.68 \ln \text{Chl } a}{\ln 2}\right)$$

Equation 2

3) $$\text{TSI (TP)} = 10\left(6 - \frac{\ln \frac{48}{\text{TP}}}{\ln 2}\right)$$

Equation 3

However, there are few chlorophyll *a* measurements available for lakes in the Park, and obtaining chlorophyll measurements is difficult. Total phosphorus is also a dependable measure of lake

productivity, but great care must be taken in collecting samples, and these must be analyzed under controlled conditions to be reliable. Secchi disc measurements are easy to collect and inexpensive but may be influenced by water color, observer bias, or error. Because Secchi measurements are easy to collect, APA staff would prefer to use Secchi measurements to determine trophic state or to verify trophic status based on other measures. The classification of lakes into trophic groups using TSI(SD) values depends on how well the TSI(SD) measurements are correlated with more direct measures of productivity, such as TSI calculated from lake phosphorus concentration. This section compares TSI values calculated from ALSC Total phosphorus and Secchi disc measurements.

Methods

Many Adirondack lakes contain high levels of organic matter. Garn and Parrott (1977) caution that TSI values developed using Secchi disc measurements for waters stained by humic organic matter result in a higher TSI, suggesting higher productivity than actually exists. Lakes stained with dissolved organic materials have highly colored brown water that reduces light penetration and transparency, affecting light availability for photosynthesis and phosphorus-chlorophyll-transparency relationships. Dissolved organic compounds complex dissolved phosphorus, reducing its availability for algae (Garn and Parrot 1977). These stained “brown water” lakes have shallow Secchi disk depth measurements that make them appear more productive than is the case and can stand phosphorus loadings that are greater than would be expected. From a regulatory point of view, the presence of dissolved organic materials in a lake may increase the concentration of phosphorus allowable in the lake because a portion of the phosphorus is not available for plant growth.

Platinum-cobalt color units are a standard method for measuring color in lake water. During the ALSC survey, platinum-cobalt color data were collected in the field under ambient light conditions at the same time as the Secchi disc transparency measurements,and in the laboratory under controlled lighting conditions from the samples used to measure Total phosphorus. The field and laboratory color measurements were compared to each other.

ALSC lake chemistry data contains Total phosphorus measurements for over 1412 ponds[1]. For most ponds, duplicate samples were collected and analyzed for quality control and assurance (Baker et al. 1990). Comparison of the two samples showed close agreement, and it is assumed that they reflect the true trophic state of these lakes. There were 485 Secchi disc measurements for the same ponds. Secchi disc and phosphorus TSI values were calculated for these ponds using equations 1 and 3. Slightly fewer ponds were used in color comparisons due to missing data.

The NYS Federation of Lake Associations recommends that the threshold for interference with Secchi TSI measurements should be set at 30 platinum-cobalt color units (NYSDEC 1990b). Lake color has also been used as a criteria in selecting acidified waters for liming. There has been an ongoing program to add lime to the waters of lakes that have become acid due to acidic deposition, and to avoid liming naturally acidic waters. It is not always clear whether a lake is acid naturally, or because of acidic deposition. In order to avoid liming natural bog waters, "summer surface water color must not exceed 75 platinum-cobalt units" (NYSDEC 1990a) for waters included in the liming program. Therefore, ponds in the ALSC database were divided into three groups on the basis of color: low color (less than 30 platinum-cobalt units), medium color (between 30 and 75 platinum-cobalt units), and high color (greater than 75 platinum-cobalt units). The method of Brezonik and Chesney (1977), as reported by Garn and Parrot (1977), was used to compute color corrected TSI(SD) values (Equation 4).

Equation 4) $\ln(Secchi_{C=0}) = (Secchi_{measured}) - 0.0035 * color$

Field and Lab Platinum-cobalt Color Comparison

Field and laboratory platinum-cobalt color measurements were collected for 480 ponds in the study watersheds. While the field platinum-cobalt color values are correlated with the laboratory values (Figure 16), field values were higher than laboratory values for 323 out of 480 ponds. Field measurements, on the average, suggest a lake that is darker, and less productive,

[1] ALSC data contains two measurements of Summer Total phosphorus (TOTAL P1, and TOTAL P2). Only TOTAL P1 data were used here. The data were not averaged, and all measurements available were included in the analysis.

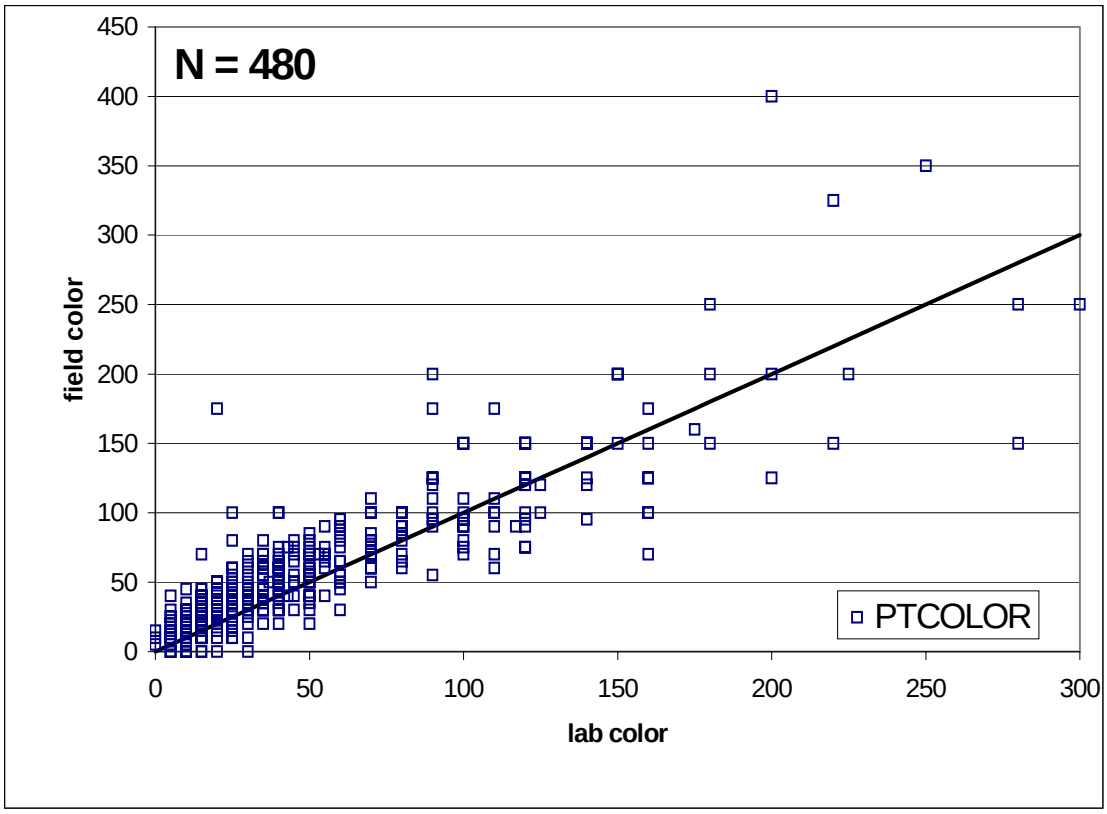


Figure 16. Comparison of Field and Lab platinum Cobalt Color Measurements for 480 Ponds Using Data from the ALSC. Higher color measurement indicates that the source water was darker. All values would fall along the diagonal black line if the field and laboratory values were the same.

than would be expected from the laboratory measurements for the same lake. Using these field platinum-cobalt color values to correct Secchi transparency before calculating TSI(SD) values would lead to over correction on the average, resulting in a higher TSI value suggesting a lake that was more productive than it actually was.

TSI Comparison

One measure of the effectiveness of TSI(SD) to classify ponds into the correct trophic state is to compare the TSI(SD) values with TSI(P) values. TSI(SD) values that are higher than TSI(P) values for the same pond suggest that the pond is more productive than its phosphorus concentration would suggest, and vice versa. Comparison of TSI(SD) and TSI(P) values for 485

ponds (Figure 17) shows that TSI(SD) values were higher than TSI(P) values in 320 out of 486 lakes.

Ponds with low phosphorus concentration, and hence low productivity, consistently had higher TSI(SD) than TSI(P), which makes them hard to identify using TSI(SD). All ponds with lower than TSI(P) of 30 had higher TSI(SD) values that were the equivalent of ponds that had much higher TSI(P) values. Similarly, ponds with high TSI(P) values that were the equivalent of a eutrophic state had TSI(SD) values that were consistently lower, and could have been mistaken for mesotrophic ponds. The classification of ponds that are oligotrophic according to phosphorus levels but mesotrophic according to Secchi depth places doubt on the value of TSI(SD) for describing the trophic state of these ponds.

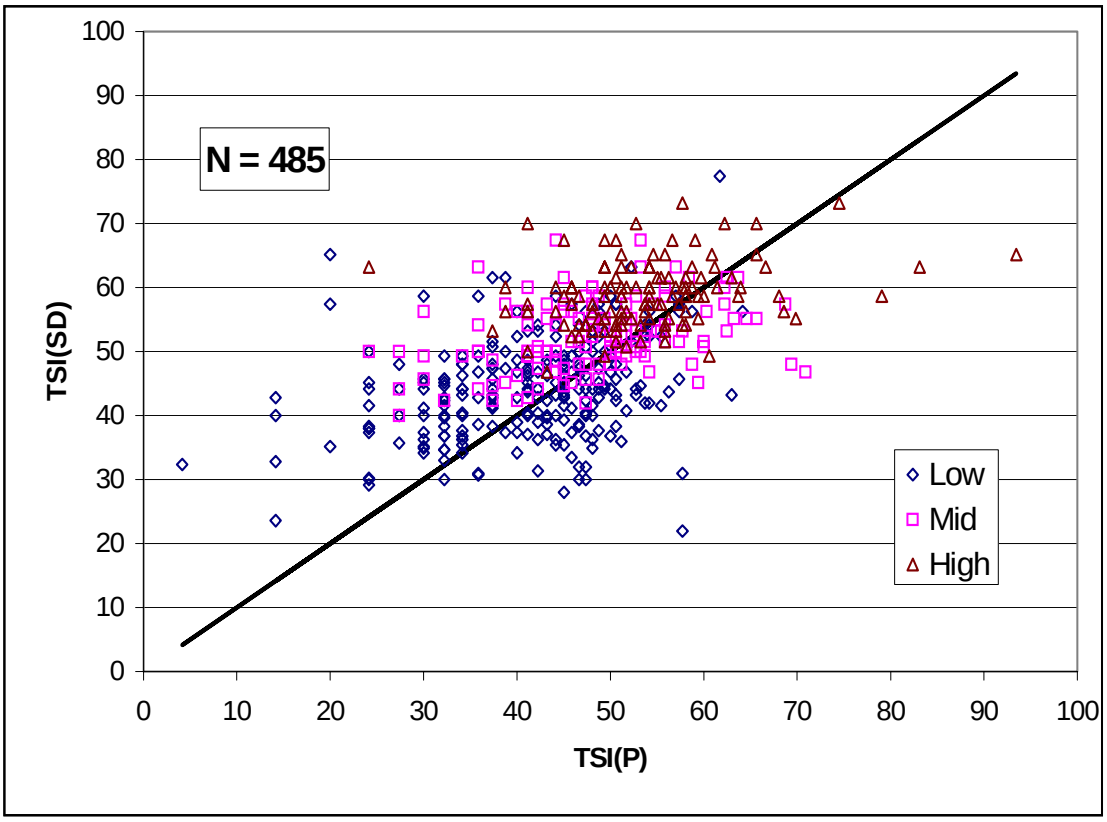


Figure 17. Comparison of Tsi Values from Secchi Disc and total phosphorus Measurements for 485 Adirondack Lakes Computed from ALSC Data. Ponds were divided into three groups on the basis of the platinum cobalt color value for that pond: Low = less than 30, Mid = 30 to 70, and High = greater than 70. All points would fall along the diagonal line down the center of the figure if the both TSI values were equal.

Ponds with high color should have shallow Secchi disc depths, and hence higher TSI(SD) values, but may vary in phosphorus concentration, and have a range of TSI(P) values. This was tested by plotting the pairs of TSI values for each pond in three groups (Figure 17). Ponds were divided into Low (less than 30 platinum-cobalt units), Mid (between 30 and 70 platinum-cobalt units), and High (greater than 70 platinum-cobalt units) groups. Ponds were roughly separated by color. Ponds with high color had generally higher TSI(SD) values than ponds with mid color, and ponds with mid color had TSI(SD) values generally higher than ponds with low color.

Secchi depth measurements for ponds with low color should be affected least by color, and should show a stronger relationship between TSI(SD) and TSI(P) than ponds with high color. For ponds with high color, the color should overwhelm the effect of phosphorus in setting the Secchi depth, and the relationship between TSI(SD) and TSI(P) will be weaker. This was tested through regression of TSI(P) on TSI(SD). While the relationship was stronger for ponds with low color, and decreased as pond color increased, and the p value for all regressions was less than $\alpha = 0.005$ for all groups, the r^2 of the relationship was very low for all pond color classes (Table 14)

Color Group	m	r^2
Low	0.25	0.09
Mid	0.21	0.12
High	0.15	0.06

Table 14. Regression Results for the Model TSI(SD) = b + m*TSI(P).

suggesting that there was high variability in the measurements included in each group.

Color correction

Correcting for TSI(SD) values for color using equation 4 had the effect of increasing the value of TSI(SD) for highly colored ponds (Figure 18), but did not improve the relationship between TSI(SD), and TSI(P). R^2 of the regression of TSI(SD) on TSI(P) for color corrected

TSI(SD) values was lower than when no color correction was used (r^2 = 0.27, and 0.28, respectively).

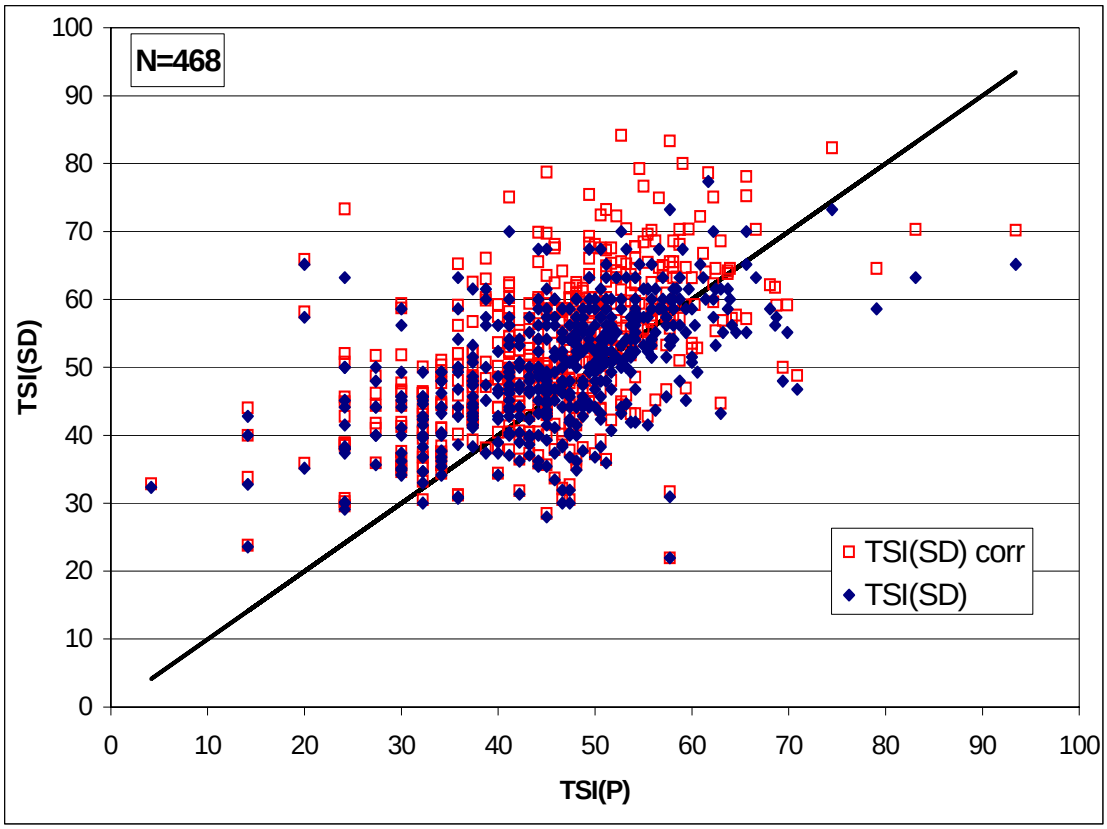


Figure 18. Comparison of Tsi Values Calculated from Color Corrected Secchi Transparency Values, and Uncorrected TSI(SD) Values. Corrected values are shown as empty squares, uncorrected values as filled diamonds. The effect of color correction is to increase the TSI(SD) values for highly colored ponds.

Data reduction

Examination of the Secchi transparency depth in comparison with the maximum depth of the pond, as recorded by the ALSC, showed that some of the Secchi transparencies were the same or deeper than the recorded maximum depth of the pond. Also, some ponds were extremely shallow (less than 1.5 meters). The Secchi transparency recorded for these ponds may not be accurate becuase there may not have been enough water depth to fully measure transparency. Removing ponds with Secchi transparency within 90% of recorded maximum depth (63 ponds), and maximum depth of less than 1.5 meters (22 ponds) did not significantly improve the

relationship between TSI(SD) and TSI(P) (r^2 = 0.26, n=400), although it did remove some ponds that appeared to be outliers.

Landscape Features

It is possible that in Adirondack lakes Secchi transparency is linked to environmental factors other than phosphorus concentration. The relation of TSI(SD) with other lake and landscape factors was investigated using multiple regression. Measurements of laboratory platinum-cobalt color, elevation, laboratory pH, lake volume, maximum lake depth, mean lake depth, and lake volume development were obtained from the ALSC lake database. Watershed area and flushing rate were obtained for each pond from the data created from this project. These factors were regressed against TSI(SD). Watershed area and TSI(P) were the only factors whose coefficients were significant. The r^2 of the final model was 0.322 (n=485), only slightly better than regression against TSI(P) alone (r^2 =0.26).

Discussion

The primary intent in using Secchi transparency is to idnetify easily and quickly the trophic state of ponds for which projects have been proposed by the Agency staff, or the project sponsor. In order for TSI(SD) to be useful in evaluating a pond, it must accurately reflect the trophic state of the pond. Comparison of TSI(SD) with TSI(P) for this data set demonstrates that TSI(SD) is not a reliable reflection of pond trophic state. Ultra-oligotrophic lakes are defined as lakes with less than 5.0 ug/l phosphorus, which corresponds to a TSI of approximately 30. Of 42 ponds with TSI(P) values in this range, only 4 TSI(SD) values were less than 30. The remaining 38 ponds range from TSI(SD) values in the mid 30s to a high of over 65. Of these, twenty-five ponds had TSI(SD) values greater than 40. The story is similar for eutrophic ponds: all ponds with TSI(P) greater than 75 had TSI(SD) values of less than 75. The spread of TSI(SD) values for ponds with low and high phosphorus concentrations makes the identification of trophic state of a pond using TSI(SD) unreliable using this dataset.

Several steps can be taken to improve upon these data. First, the Secchi measurements used here were collected during the summer, but not at the same time as the lake chemistry samples were collected. Secchi disc depth varies somewhat through the growing season, and could account for some of the differences between the two TSI values. Better agreement between TSI(SD) and TSI(P) might be obtained if the Secchi disc measurements and lake chemistry

samples were collected during the same visit to the pond. Second, Garn and Parrot (1977) report that the accuracy of Secchi transparency can be improved by taking repeated measurements. For 4 lakes in the Ottawa National Forest, Michigan, 5 to 12 Secchi measurements were necessary to obtain a mean value within 5 percent of the mean of a larger sample. Only one Secchi transparency measurement was recorded for each pond in the ALSC dataset. A useful improvement would be to collect repeated Secchi transparency measurements on the same day. Third, the studies which Garn and Parrot (1977) used were conducted on lakes in Minnesota (Carlson 1977) and Florida (Brezonik and Chesney 1977). While Minnesota is climatically similar to the Adirondacks, the range of elevations in the Adirondacks is much greater than in Minnesota and may affect the productivity of lakes, changing the relationship of Secchi depth to phosphorus. Similarly, the color correction equation developed by Brezonik and Chesney 1977 was developed for lakes in Florida. The climate of Florida has less pronounced seasons and is warm relative to the seasonal cold climate of the Adirondacks. A useful improvement in the existing Secchi disc information would be to collect total phosphorus samples and repeated Secchi disc measurements from a large enough trophically diverse set of lakes to construct an equation for Carlson's TSI and color correction using only Adirondack data. Until this is done, the existing Secchi depth data obtained from the ALSC should not be used to determine trophic state. From a management point of view, the lesson is that a single Secchi depth measurement for a lake is not a good indicator of trophic state. Secchi depth may be a only be a good indicator of trophic state if repeated measures are collected at the appropriate time of year. Further work is needed to confirm this.

Part 2: Lake Sensitivity Index

Vollenweider (1969, 1975) developed a predictive model for the phosphorus concentration in a lake that included nutrient loading and retention, lake volume, runoff, and flushing rate. Garn and Parrot (1977) modified this model so that it could be used to evaluate the sensitivity of a lake to changes in nutrient loading using forested lake watersheds in the Boundary Waters Canoe Area of Superior National Forest. They found the index useful for qualitative comparison between lakes, and for grouping lakes into sensitivity classes. This approach has been used on a case by case basis by APA staff to make an impact determination where a large proposed project has the potential to change the trophic status of a waterbody.

New data gathered for this project and Adirondack Lakes Survey Corporation (ALSC) data from the 1980's makes it possible to compute lake sensitivity values for a large number of lakes simultaneously. These values will be of use to Agency staff in evaluating future proposed projects and increased understanding of the landscape. This section uses the ALSC lake survey data and watershed data gathered for this project to compute sensitivity values for lakes in these watersheds.

Methods

Garn and Parrot (1977) warn that their model has several limitations. It assumes that overland flow is the main source of water for the lake or pond. Therefore, it will not work for lakes in which groundwater is the primary water source, such as seepage lakes. The model is not appropriate for lakes that are shallow (1 meter or less in depth), or eutrophic (greater than 30 ug/l phosphorus). In these lakes physical or biological factors which were not included in the model dominate the lake. Shallow lakes, and lakes with high phosphorus concentration were identified using the ALSC data. Seepage lakes were identified using the classification from Driscoll et al. (1990).

The Adirondack Lakes Survey Corporation (ALSC) collected lake volume and depth for over 1400 lakes. Of these, 660 lie within the Upper Hudson, Oswegatchie and Black River watershed for which we have GIS watershed maps. Lake sensitivity (S) was calculated for these ALSC lakes using,

$$S = \frac{1 - R}{\bar{z}\rho}$$

where $\bar{z}$ = the mean lake depth (m), ρ = the lake flushing rate, and R, the nutrient retention coefficient

$$R = 0.426\exp(-0.271q_s) + 0.574\exp(-0.00949q_s)$$

where q_s is equal to the runoff per unit area of the watershed (m) times the area of the watershed (m^2) divided by the surface area of the lake (m^2). Lake surface area and mean depth, were obtained from the ALSC lakes survey data, and watershed area was obtained from the digital watershed data prepared for this project. Runoff and flushing rates were obtained from modeling work described earlier in this report.

Results

Two-hundred and sixty-one lakes were removed from consideration because of high phosphorus concentrations, shallow depth, or because the dominant water source was groundwater. Of the remaining 399 lakes (Table 15), 54 percent were insensitive, or very insensitive to nutrient input (classes 1 and 2), 33 percent were moderately sensitive (class 3), and 13 percent were sensitive to very sensitive (class 4 and 5). Sensitivity values for all 660 lakes are shown in Appendix 18. As might be expected, most thick till lakes were insensitive to very insensitive. Till lakes with high DOC were also proportionately more likely to be insensitive or very insensitive. Thin till lakes with low DOC were most likely to be in the moderately to very sensitive classes (92 out of 171 lakes).

The location of low nutrient lakes is important for understanding their vulnerabilities, is valuable for project review officers, and is critical for planning and risk assessment purposes. There were not enough watersheds in most portions of the study area to evaluate the regional pattern of lake sensitivity in more than general terms. Moderately sensitive and sensitive lakes

Sensitivity Class Lake type description	1	2	3	4	5	Total	Removed
Carbonate influenced	9	10	15	5		39	8
Flagged data not rated							5
Flow seepage							3
Flow seepage high DOC							17
Flow seepage low DOC							10
Medium till drainage	1	1		1		3	6
Medium till drainage high DOC	5	5	5	3		18	27
Medium till drainage low DOC	5	10	11	5		31	2
Mounded seepage							1
Mounded seepage high DOC							10
Mounded seepage low DOC							16
Salt impacted	12	12	9	7		40	22
Seepage							1
Thick till drainage		2				2	1
Thick till drainage high DOC	9	3	1			13	11
Thick till drainage low DOC	5	6	3	2		16	4
Thin till drainage	3	4	7	1		15	7
Thin till drainage high DOC	17	17	13	4		51	91
Thin till drainage low DOC	33	46	66	25	1	171	19
Grand Total	99	116	130	53	1	399	261

Table 15. Adirondack Lakes in the Oswegatchie, Black and Upper Hudson Watersheds Divided by Lake Sensivity Classes and Lake Type. Class 1 is very insensitive, and includes S values from 0.0 to 0.025. Class 2 is insensitive, and includes S values from >0.025 to 0.05. Class 3 is moderately sensitive, and includes S values from >0.05 to 0.075. Class 4 is sensitive, and includes S values from >0.075 to 0.10. Class 5 is very sensitive, and includes S values >0.10.

were located in almost every corner of the study area (Figure 19). In particular, many of the lakes north of Stillwater Reservoir were moderately to very sensitive. The large open spaces in many parts of the study area, particularly in the southern Hudson watershed, which is among one of the more heavily settled areas in the Park, show where additional data would be useful. Lack of sampling in these areas by the ALSC is due in part to the need to obtain permission from landowners to sample lakes on private land. Much of the southern Hudson watershed is in private ownership.

As the level of nutrients in a lake increased, the number of lakes that were moderately sensitive to sensitive to additional nutrients decreased (Table 16). While most low nutrient lakes (ultra-oligotrophic lakes) were moderately sensitive to sensitive or very

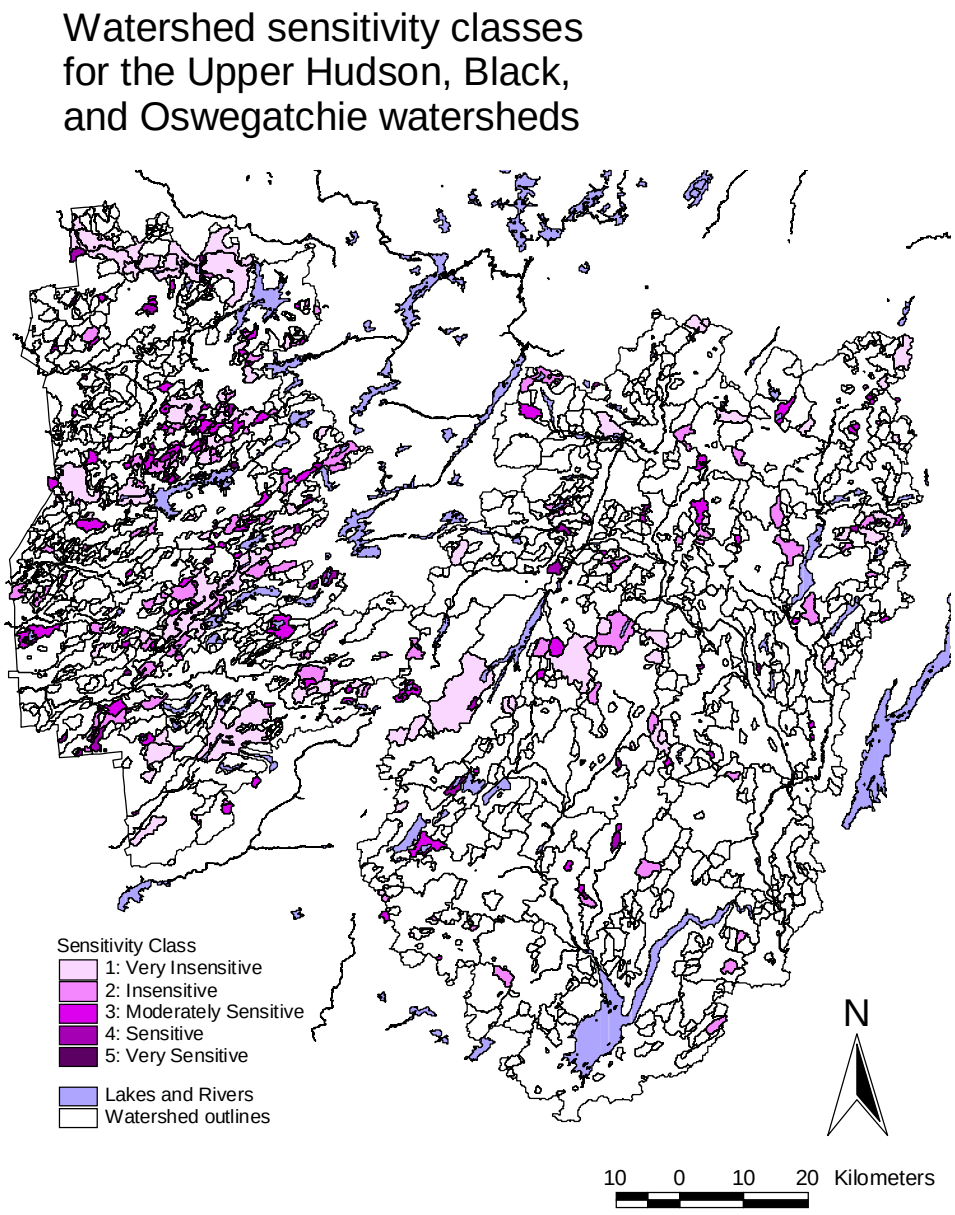


Figure 19. Lake Sensitivity to Nutrient Addition Classes for Watersheds in the Upper Hudson, Oswegatchie, and Black River Watersheds. See text for explanation of the classes.

	Sensitivity Class					
Trophic State	1	2	3	4	5	Grand Total
ultra-oligotrophic	13.00%	28.74%	35.63%	21.84%	1.15%	87
oligotrophic	26.95%	29.79%	30.50%	12.77%		141
mesotrophic	25.83%	27.50%	37.50%	9.17%		120
meso-eutrotrophic	37.25%	31.37%	21.57%	9.80%		51
Grand Total	24.81%	29.07%	32.58%	13.28%	0.25%	399

Table 16. Comparison of Lake Trophic State and Sensitivity to the Addition of Nutrients. Ultra-oligotrophic <5 ηg/l, oligotrophic 5 - 10 η/lg , mesotrophic > 10 to ≤20 ηg/l, meso-eutrophic > 20 - ≤30 ηg/l. Units are Total phosphorus. Class 1 is very insensitive, and includes S values from 0.0 to 0.025. Class 2 is insensitive, and includes S values from >0.025 to 0.05. Class 3 is moderately sensitive, and includes S values from >0.05 to 0.075. Class 4 is sensitive, and includes S values from >0.075 to 0.10. Class 5 is very sensitive, and includes S values >0.10.

sensitive, most meso-eutrophic lakes were very insensitive or insensitive. Still, approximately 30 percent of meso-eutrophic and 45 percent of mesotrophic lakes were moderately sensitive or sensitive.

Discussion

Generally, staff at the Park Agency are concerned with several classes of lakes. Low productivity lakes, otherwise known as oligotrophic lakes, are of special concern because the aquatic communities that develop there are dependent on low nutrient concentrations, and an increased input of phosphorous is likely to have more effect on changing the chemistry and communities of these lakes than a richer, more productive lake system.

On the other end of the productivity scale, staff are concerned with differentiating between lakes that are eutrophic due to high phosphorus levels and those that appear eutrophic because of color. Highly colored lakes appear eutrophic because the color mimics the effects of high productivity when measured by color or secchi depth, but are less productive than they appear because the high color limits the depth of water in which photosynthesis, and hence plant productivity can take place. This condition is otherwise known as dystrophy. At this time it is difficult to suggest at what color level this concern should begin.

Agency staff are concerned about mesotrophic lakes which are vulnerable to additions in nutrients. This analysis suggests that at least a third of mesotophic and meso-eutrophic lakes are in this category.

Agency staff find value in determining what constitutes the insensitive class for the purposes of: 1) understanding what predicts a lakes ability to cycle nutrient loads without changing trophic character, and 2) potentially identifying those waters when directing watershed development.

Implementation

A goal of this project was to produce a protocol for the assessment of cumulative effects and their prediction for the Adirondack Park using existing and new digital map and other data layers. At the outset, project staff anticipated the development of an interactive computerized model into which selected data regarding the physical conditions and setting of the site of a proposed development activity, historical site data including watershed conditions, and a characterization of development activity could be entered. The model would generate an assessment of the effects of the proposed development and determine if the proposed activity would push existing water quality and/or habitat quality parameters over a threshold resulting in a degraded natural ecosystem. The threshold would be based on existing water quality and wetland function and typically would include a change in lake or pond trophic status or loss or change in wetland function.

This optimistic vision did not happen for several reasons. First, cumulative impacts occur when there are several impacts to the same resource (wetland, lake) that occur in close proximity in space or time so that the affected system does not have time to recover. Procedures are presently in place in the project review process where large development projects are proposed that may by themselves lead to cumulative impact, but in order to identify cumulative impacts that have occurred over time it is necessary to show that the state of the resource has changed, and that the change can be linked to an activity that can reasonably be expected to cause impact. This requires a series of data collected at different times, which is only available in special cases. Second, the factors involved in an analysis of cumulative effects are complex and interactive. A major interest of Agency staff is to be able to predict the impacts of changes in the delivery of nutrients. Several of the existing map data layers do not contain sufficient detail, most notably soils, precipitation, or the location of nutrient sources, to make the prediction of cumulative impacts reliable at the small scale that most proposed projects require.

There are many examples of techniques that can be used to rate the “functionality” of natural systems. These rate natural systems according to some predetermined set of criteria. The Agency already has a similar system for evaluating wetlands in place in its rules and regulations (APA 1982). Although this system favors wildlife habitat over other ecosystem functions, it has

been in use for a long time. Following discussions with the Peer Review Group, we determined not to investigate these methods further at this time.

Instead, we looked for methods to use the existing and new digital map data to identify natural systems that were potentially sensitive to impacts (anticipated impacts as described above), or areas where the potential for impacts was great because of the concentration of impact activities (potential impacts as described above), and incorporate these maps into the existing Agency project review system. The Agency has developed and implemented a GIS-based project tracking system called the "APA Data Look-Up System." This is an interactive mapping and database program, available at many personal computers at Agency headquarters, and is used in the early stages of the project review process to obtain information about the natural and historical setting of the project. Typically, the Agency receives an application from a project sponsor to undertake a project, and a member of the project review staff is assigned to the project. Using the lookup system, the project review staff uses a digital base map upon which they overlay selected digital map layers. The project review officer seeks additional information from the applicant and analysis expertise from technical staff depending on the location and nature of the project.

The Look-Up System allows staff to locate parcels using tax map numbers and/or owner's name and to view them along with the other available natural resource and human impact map layers. This project added several layers to this system that were designed to raise a "red flag" when project review officers make their preliminary review and require them to refer the project to staff with the proper technical expertise. These layers include the location of permit actions by the Agency that help establish the historical legacy of the parcel, maps of the degree of parcel saturation of privately held lands organized by watershed, and maps of lake sensitivity to nutrient input. This "red flag" system will be extended in the future as more maps of landscape sensitivity are prepared. Additions that are contemplated include the density of tax parcels located within a certain distance of wetlands and water bodies.

Obtaining Data

How to get copies of data developed for this project:

NYS Adirondack Park Agency

John W. Barge
NYS Adirondack Park Agency
P.O. Box 99
Ray Brook, NY 12977

Some data may be made available through the Adirondack Park Agency web site at:

http://www.northnet.org/adirondackparkagency/gis/index.html

Other sources of data discussed in this report include:

Adirondack Lakes Survey Corporation (ALSC) data

New York State Biological Survey
NYSDEC Region 5
Rte. 86
Ray Brook, NY 12977
(518) 897-1354

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